ISSN 2307–3489 (Print), ISSN 2307–6666 (Online)
Наука та прогрес транспорту, 2025, № 1 (109)

UDC 621.6.033:623.1-049.65

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Evaluation of gabions usage effectiveness for industrial facilities protection against damage

Purpose. In the extreme situations at industrial sites, various damaging factors may appear, such as the spread of toxic substances in the air, the creation of a fireball, etc., which pose a threat to the lives of workers and have a significant negative impact on the environment. That is why today, special attention is being paid to the problems associated with the spread of debris during a drone attack. At an industrial site where oil product storage facilities are located, the debris generated during an explosion can damage the tank building and cause a fire. In this regard, the main objective of the study is to evaluate the effectiveness of using gabion to reduce the risk of damage to the oil storage facility during the movement of drone debris. **Methodology.** To achieve this goal, the paper considers the problem of flying debris in the event of a drone explosion at an industrial site where oil storage facilities are located. The use of gabion with sand is proposed to protect the tank building from the throwing effect of debris. It is proposed to develop a mathematical model of the movement of a fragment in the path of which the gabion is located. The effect of gabion as a protective screen on reducing the air temperature near a neighboring oil storage facility in the event of a fire at an industrial site is also considered. A model of the dynamics of a point motion (Newton's second law) was used to mathematically describe the movement of the debris. Numerical integration of the modeling equations was performed using the Euler's method. The energy equation was used to model the process of thermal air pollution at an industrial site during a fire. **Findings.** In this work, the numerical model was programmed and a computer code was created. The programming language is FORTRAN. The code provides information on the speed of the fragment movement in different parts of each zone. On the basis of the constructed numerical model and the created code, parametric studies were carried out to determine the effectiveness of using gabion with sand to protect the oil storage facility from the effects of fragment. As an approximation, the case when the fragment after the explosion moves horizontally in the direction of the object was considered. The influence of the gabion height on the heating level of the wall of the oil storage facility located at an industrial site was analyzed. **Originality.** An effective mathematical model has been developed to evaluate the effectiveness of using gabion to protect the oil storage facility from damage by drone fragment. The proposed model allows determining the rational dimensions of the gabion to reduce the risk of damage to the tank wall. An effective computer model of thermal air pollution at an industrial site in the event of a fire at an oil storage facility is presented. **Practical value**. On the basis of the constructed mathematical model, a computer code was created to conduct a computational experiment to determine the effectiveness of using protective barriers (gabions) on the territory of an industrial site.

Key words: risk of damage; dynamics of fragment movement; gabion; mathematical modeling; thermal contamination

Introduction

Extreme situations on the territory of industrial facilities and transport pose a threat to the lives of workers and have a significant negative impact on the environment [1, 7, 10, 11]. In extreme situations at industrial sites, various shocking factors may appear, for example, the appearance of toxic substances in the air, the creation of a fireball, etc. [1]. In the event of explosions at an industrial site, there is a scattering of fragment that creates a risk of damage to personnel and facilities due to the movement

doi: https://doi.org/10.15802/stp2025/324155

of fragment at a high speed. The problem of risk analysis in the event of extreme situations involves solving two important tasks - determining the areas of damage and developing protective methods to reduce the consequences of an extreme situation

It should be noted that in the future, special attention will be paid to the problems associated with the dispersal of fragment during drone attacks. If there is such an extreme situation at an industrial site where oil storage facilities are located, the fragment generated by the explosion may damage the oil storage facility's building. This will lead to the release of fire products at the industrial site, the release of fire products into the atmosphere and the appearance of thermal pollution of the environment. Thus, it is very important to develop means of protecting oil storage facilities in the event of flying fragment from drone explosions.

It should be noted that to solve this problem, it is possible to use gabions as obstacles to the movement of fragment. These structures are widely used in the world to form the landscape of parks, to build roads, to strengthen slopes as retaining walls or as elements of culverts [5, 6, 8, 9]. The advantage of gabions is that they are filled with materials that do not require significant funds. These structures can have different shapes and sizes, which is very important for their practical use. The most important thing is that local materials can be used to fill them. It is clear that such structures have found their place in the military to protect against damage (Fig. 1, Fig. 2).

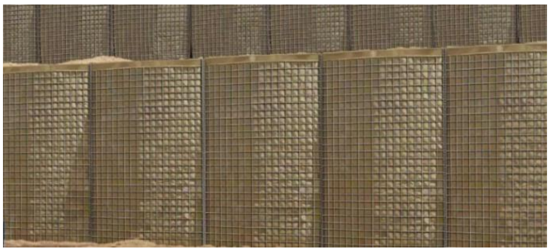

Fig. 1. Axial gabion (https://cutt.ly/Ge6IYzQ3)

Fig. 2. Axial gabion (https://cutt.ly/me6IYClq)

For scientific substantiation of gabion parameters, separate calculations are always required. An analysis of existing scientific publications has shown that they consider methods for calculating the stability of gabions when used as retaining walls, calculating the deformation of gabions, determining their dimensions and the amount of material to be filled [5, 8, 9]. In the direction of studying the effectiveness of using gabions for protection against damage to oil storage facilities, we can identify work [2], which considers the calculation of gabions with different fillings – sawdust, oilcake, dry earth. Also, the results of research in the field of protection of oil storage facilities from damage are presented in [3], where the effectiveness of using a metal plate as an obstacle to the movement of a fragment is analyzed. It should be noted that the range of scientific works in this area is extremely limited. Thus, this gives grounds for conducting scientific research to improve the protection systems of oil storage facilities at industrial sites in the event of drone explosions.

Purpose

The purpose of this article is:

1. Evaluation of the effectiveness of using gabion with sand to reduce the risk of damage to oil storage facilities at industrial sites of mining enterprises during the movement of drone fragment.

2. Assessment of thermal damage zones at an industrial site in case of burning of a storage facility with oil products.

Methodology

The paper considers the problem of flying fragment in the event of a drone explosion at an industrial site where oil storage facilities are located. The use of gabion with sand is proposed to protect the tank building from the throwing effect of the fragment. The task is to develop a mathematical model of the movement of a fragment in the path of which the gabion is located.

The fragment generated by a drone explosion has a different geometric shape, mass, and speed.

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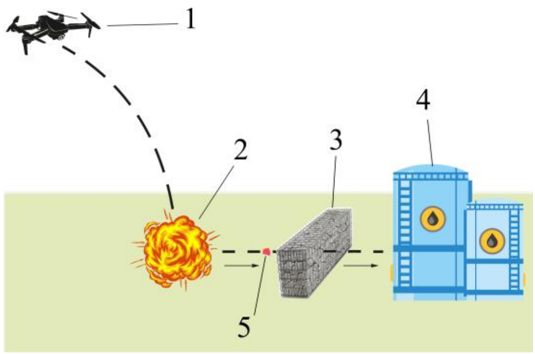

Fig. 3. Location of the gabion on the industrial site:
1 – drone; *2* – explosion site; *3* – gabion;
4 – oil storage facility

In addition, these fragments can be formed at different heights and move at different angles to the object to be protected (hereinafter referred to as the object). To build a mathematical model of the fragment movement and its interaction with the protective barrier body (gabion), we make the following assumptions:

1) the fragment has a cone shape;

2) the mass of the wreckage is known;

3) the speed and direction of the fragment from the point of explosion are known;

4) the length from the fragment impact point to the gabion and the object is known;

5) The angle of α the fragment relative to the ground is known;

6) the density of the ρ_{cm} material of the protective barrier (gabion) is known.

The trajectory of the fragment from the explosion site to the object is divided into three parts:

1) zone 1 - from the explosion site to the gabion;

2) zone 2 - movement of the fragment inside the gabion with sand;

3) zone 3 - movement of the fragment from the gabion to the object (if the fragment passes zone 2).

We will describe the dynamics of the fragment movement in each zone using Newton's second law:

$$m\frac{dV}{dt} = -F_R - F_g, \qquad (1)$$

where m is the mass of the fragment; $V(u, v)$ is the velocity vector of the fragment in the medium; $F_g = mg$ is the gravity; $F_R = C_x \frac{\rho_в V^2}{2} S$ – the drag force of the fragment; C_x – the drag coefficient of the fragment; $\rho_в$ – the density of the medium; S – the copper cross-sectional area of the fragment; t – time.

It should be noted that the value of the drag coefficient C_x for the second zone (movement of the fragment in the sand) differs from the value of this coefficient for the first and third zones (movement of the fragment in the air).

For practical use of equation (1), let's write it in the projection on the coordinate axis for each zone:

$$m\frac{du}{dt} = -C_x \frac{\rho_в u^2}{2} S, \qquad (2)$$

$$m\frac{dv}{dt} = -C_x \frac{\rho_в v^2}{2} S - mg, \qquad (3)$$

where u, v are the projections of the fragment velocity vector on the coordinate axes; S is the area of the midline section.

Note that the Y-axis is directed vertically upward, and the X-axis is directed in the direction of horizontal movement of the fragment.

Next, the numerical integration of equations (2) and (3) is performed to determine the speed of the fragment in each zone. The drag coefficient C_x for the first and third zones is assumed to be 0.5, for the second zone it is assumed to be 0.85 (Gerasimov S.I., Erofeev V.I. and others).

The mathematical model uses the value of the cross-sectional area S to calculate the drag force, so the value of the parameter S is determined as follows. If the mass of the fragment is m, then this mass can be determined as follows

$$m = \rho_s W,$$

ρ_s – the density of the fragment material; W – the volume of the fragment.

The volume of the fragment can be determined experimentally, for example, using Archimedes' law - that is, by measuring the volume of water that was displaced from the container in which the fragment was placed. Thus, the parameter W can be taken known. However, if the model represents the shape of the fragment as a cone, then the parameter W is calculated as follows:

$$W = \frac{1}{3}\pi R^2 h,$$

where R – radius of the base of the cone; h – height of the cone.

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The parameter h can be assumed to be known based on the analysis of the shape of the fragment. Then, the radius of the base of the cone will be determined based on the following dependencies as follows

$$R = \sqrt{\frac{3m}{\rho \pi h}}.$$

The value of the area of the copper section will be $S = 0.785(2R)^2$.

Numerical solution

Equations (2), (3) for each zone are solved numerically using the Euler method [7]. The determination of the values of the components of the velocity of the fragment u, v on the new time layer «n+1» is based on the following dependencies:

$$u^{n+1} = u^n - \Delta t \cdot C_x \frac{\rho_в u^2}{2m} S, \tag{4}$$

$$v^{n+1} = v^n - \Delta t \cdot C_x \frac{\rho_в v^2}{2m} S - \Delta t\, g. \tag{5}$$

To perform the calculation based on dependencies (4) and (5), it is necessary to set the angle α of the fragment departure, which makes it possible to determine the projections of the fragment velocity vector at the beginning of the calculation

The range Δx of the fragment for the time step Δt is equal to:

$$\Delta x = \Delta t \cdot u(t).$$

The distance of the fragment from the explosion site is determined as follows:

$$x(t) = x_0 + \sum \Delta x,$$

where x_0 is the coordinate of the fragment departure location.

The numerical model was programmed and the code «Drone-2» was created. The programming language is FORTRAN. The code provides information about the speed of the fragment in different parts of each zone. It should be borne in mind that this speed value allows us to determine the kinetic energy of the fragment in each zone. Particular attention should be paid to the value of the out-of-obstacle velocity of the fragment, i.e., the velocity of the fragment after passing the gabion «body», since the main purpose of using gabion is to significantly reduce the velocity of the fragment, which makes it possible to reduce its kinetic energy.

At the second stage of this research area, a numerical model was developed to assess the thermal damage zones at an industrial site in the event of an oil storage facility fire. To model the heating of air at an industrial site, the energy equation was used:

$$\frac{\partial T}{\partial t} + \frac{\partial uT}{\partial x} + \frac{\partial vT}{\partial y} = div\left(a\, grad\, T\right), \tag{6}$$

where T – temperature; u, v – components of the air flow vector; $a = \left(a_x, a_y\right)$ – thermal conductivity coefficients; x_i, y_i – Cartesian coordinates; t – time.

The boundary conditions for the energy equation are as follows:

1. At the boundary where the air flow enters the area:

$$T = T_{in},$$

where T_{in} – the background air temperature.

2. At the boundary where the air flow leaves the calculation zone:

$$T_{i+1,j} = T_{i,j},$$

where $T_{i+1,j}$ – temperature in the last difference cell; $T_{i,j}$ – temperature in the previous cell.

3. On the surface of objects, ground surface, upper boundary of the calculation area:

$$\frac{\partial T}{\partial n} = 0.$$

Initial condition ($t=0$): $T=T_0$, where T_0 – air temperature where the fire occurs, in the rest of the computational domain the temperature is equal to the background temperature

Since there are several storage facilities on an industrial site, it is necessary to take into account the influence of these facilities on the airflow velocity field. To solve this problem, we will use the following equation:

$$\frac{\partial^2 P}{\partial x^2} + \frac{\partial^2 P}{\partial y^2} = 0, \tag{7}$$

doi: https://doi.org/10.15802/stp2025/324155

$$u = \frac{\partial P}{\partial x}, v = \frac{\partial P}{\partial y}, \tag{8}$$

where P – velocity potential.

The boundary conditions for the aerodynamic equation are:

1) $\frac{\partial P}{\partial n} = 0$ – on hard borders;

2) $\frac{\partial P}{\partial n} = V_n$ – at the boundary where the flow enters region, V_n – known air velocity;

3) P=const – at the boundary where the flow exits its region.

On the basis of equation (7) and dependencies (8), the deformation of the air flow velocity field in the presence of objects at an industrial site is determined

For the numerical integration of equations (6) and (7), finite-difference splitting schemes are used. The code for the implementation of the numerical model on a computer has been developed, the programming language is FORTRAN.

Findings

At the first stage of calculations, parametric studies were conducted to determine the effectiveness of using gabion with sand to protect the tank building from the effects of fragment (Fig. 1). As a first approximation, we considered the case when the fragment after the explosion moves horizontally in the direction of the object (α=0).

The calculation is based on the following data: the explosion occurs at a distance of 40 meters from the oil storage facility, the protective barrier is located at a distance of 15 meters from the oil storage facility. The height of the fragment ejection is 3 m, the mass of the fragment is 50 grams. Two scenarios were considered. The first scenario: ρ=1 600 kg/m^3 – sand density in gabion (dry sand); the initial velocity of the fragment varies: 300 m/s; 450 m/s; 600 m/s. The density of the fragment material is 7 700 kg/m^3, the diameter of the base of the fragment «cone» is 2 cm. It is assumed that the protective function of the gabion is fulfilled if the speed of theV_b obstructing the fragment (i.e., the speed behind the gabion) is about 0.2 m/s, i.e., at this speed the kinetic energy of the fragment is not sufficient to damage the surface of the oil storage facility. The task is to determine the required width of the gabion.

The calculation results for these parameters are shown in Table 1.

Table 1

Values of the out-of-bounds velocity of the fragment (Scenario 1)

Initial velocity of the fragment	Out-of-bounds speed V_b	Gabion thickness
300 m/s	0.15 m/s	1.86 m
450 m/s	0.16 m/s	1.95 m
600 m/s	0.16 m/s	2.01 m

According to the results shown in Table 1, it can be argued that with a gabion thickness of about 2 m, for the given parameters of the problem, the gabion will be effective.

Second scenario: initial fragment velocity 700 m/s; sand density in the gabion varies: ρ=1 600 kg/m^3 (dry sand); ρ=1 920 kg/m^3 (wet sand); ρ=2 080 kg/m^3 (wet, compressed sand).

The calculation results for the second scenario are shown in Table 2.

Table 2

Values of the out-of-bounds velocity of the fragment (Scenario 2)

Type of sand in gabion	Out-of-bounds speed V_b	Gabion thickness
dry sand	0.16 m/s	2.03 m
wet sand	0.14 m/s	1.72 m
wet, compacted sand	0.14 m/s	1.58 m

According to the results shown in Table 2, it can be argued that when wet, compressed sand is used in the gabion body, its thickness can be reduced by about 20 %.

Note that the calculation time is 1 second.

The following are the results of a computational experiment to calculate the area of thermal pollution at an industrial site (model problem) when the oil storage facility is damaged by fragment and a burning spill zone appears. The temperature at the fire site is 1 300 ℃. The effect of a protective screen (gabion) at an industrial site on reducing the air temperature near the wall of a tank with oil products located near the burning area is analyzed.

doi: https://doi.org/10.15802/stp2025/324155

The simulation was performed at a wind speed of 7 m/s and an initial air temperature of 20 °C. Three scenarios were considered:

Scenario №1 – no protective screen (gabion) near the spill area;

Scenario №2 – with protective screen (gabion), height 4 m;

Scenario №3 – with protective screen (gabion), height 8 m.

The temperature field at the industrial site for each scenario is shown in Figs. 4–6.

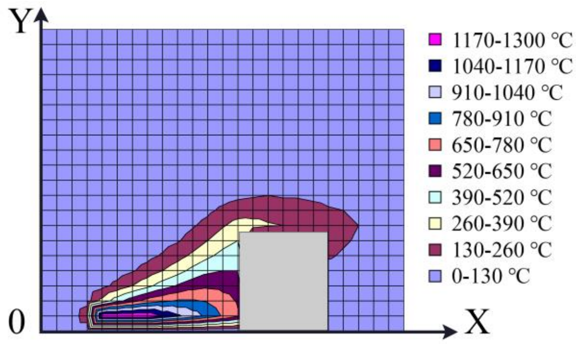

Fig. 4. Heat contamination zone (Scenario №1)

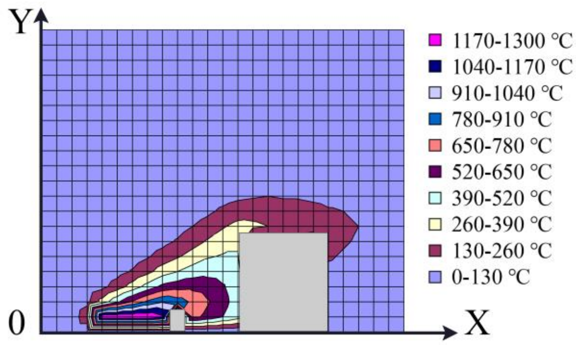

Fig. 5. Heat contamination zone (Scenario №2)

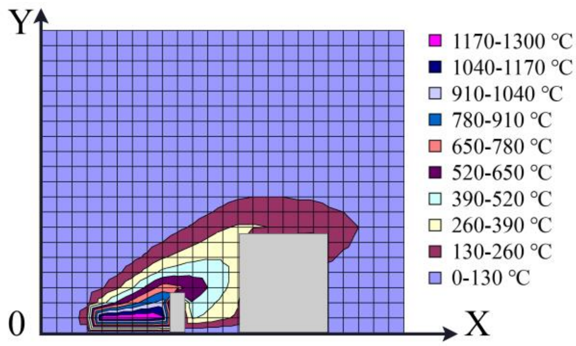

Fig. 6. Heat contamination zone (Scenario №3)

From the above figures, it can be seen that the air temperature on the windward wall of the storage facility, in the absence of a screen, varies from 663 °C (in the lower part) to 390 °C (in the upper part). In the presence of a 4 m high shield, the temperature varies from 442 °C (in the lower part) to 364 °C (in the upper part). In the presence of a screen that has a height of 8 m, the temperature varies from 234 °C (in the lower part) to 325 °C (in the upper part). Thus, the screen effectively reduces the temperature in the lower part of the repository wall under the considered scenarios.

Note that the calculation time for each scenario is 3 seconds.

Originality and Practical value

An effective mathematical model has been developed to evaluate the effectiveness of using gabion to protect the oil storage facility from damage by drone fragment. The constructed mathematical model is based on the numerical integration of the equation of unsteady motion of a material point in airspace and in the body of the gabion to determine the obstructive speed of the fragment.

The proposed model makes it possible to determine the rational dimensions of the gabion to reduce the risk of damage to the tank wall.

An effective computer model of thermal air pollution at an industrial site in the event of a fire at an oil storage facility is presented. The model makes it possible to carry out an express assessment of the risk of thermal damage to humans at an industrial site in the event of a fire.

Conclusions

1. A multivariate mathematical model of the fragment movement in the air and in the gabion «body» with different contents was created.

2. On the basis of the constructed mathematical model, a computer code was created to conduct a computational experiment to determine the effectiveness of the use of protective barriers (gabions) on the territory of an industrial site. This code can be useful at the «form sketch» stage of the

3. A computational experiment was carried out, which made it possible to determine the rational thickness of the gabion for filling which sand was used.

doi: https://doi.org/10.15802/stp2025/324155

4. The risk of thermal damage to humans at an industrial site in the event of an oil storage facility fire was assessed.

5. The considered numerical models belong to the class of «screening models» used for engineering estimates.

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doi: https://doi.org/10.15802/stp2025/324155

ЕКОЛОГІЯ ТА ПРОМИСЛОВА БЕЗПЕКА

Оцінювання ефективності використання габіонів для захисту від ураження промислових об’єктів

Мета. У разі екстремальних ситуацій на промислових майданчиках можлива поява різних уражальних факторів, наприклад, поширення в повітрі токсичних речовин, створення вогняної кулі тощо, які становлять загрозу життю працівників та мають значний негативний вплив на довкілля. Тому сьогодні особливу увагу привертають задачі, пов’язані з розлітанням уламків під час атаки дронів. На промисловому майданчику, де розташовані сховища нафтопродуктів, уламки, що утворилися під час вибуху, можуть пошкодити корпус нафтосховища та спричинити пожежу. У зв’язку з цим основна мета роботи полягає в оцінюванні ефективності використання габіону для зниження ризику ураження нафтосховища під час руху уламків дрона. **Методика**. Для досягнення поставленої мети в роботі розглянуто задачу розлітання уламків у разі вибуху дрона на промисловому майданчику, де розташовані нафтосховища**.** Для захисту корпусу нафтосховища від метальної дії уламків запропоновано використання габіону з піском. Передбачено розробити математичну модель руху уламка, на шляху якого розташований габіон. Також розглянуто вплив габіону як захисного екрана на зниження температури повітря біля сусіднього сховища нафтопродуктів у разі виникнення пожежі на промисловому майданчику. Для математичного опису руху уламка використано модель динаміки руху точки (другий закон Ньютона). Чисельне інтегрування моделювальних рівнянь здійснено за методом Ейлера. Для моделювання процесу термічного забруднення повітря на промисловому майданчику під час пожежі використано рівняння енергії. **Результати**. У роботі здійснено програмування чисельної моделі та створено комп’ютерний код. Мова програмування – FORTRAN. Код дає інформацію про швидкість руху уламка в різних частинах кожної зони. На базі побудованої чисельної моделі та створеного коду було проведено параметричні дослідження з визначення ефективності використання габіону з піском для захисту корпусу нафтосховища від дії уламків. Як наближення розглянуто випадок, коли уламок після вибуху рухається горизонтально в напрямку об’єкта. Здійснено аналіз впливу висоти габіону на рівень нагрівання стінки сховища нафтопродуктів, розташованого на промисловому майданчику. **Наукова новизна**. Розроблено ефективну математичну модель оцінювання ефективності використання габіону для захисту корпусу нафтосховища від ураження уламками дрона. Запропонована модель дозволяє визначати раціональні розміри габіону для зниження ризику пошкодження стінки нафтосховища. Наведено ефективну комп’ютерну модель термічного забруднення повітря на промисловому майданчику у випадку пожежі на нафтосховищі. **Практична значимість**. На базі побудованої математичної моделі створено комп’ютерний код для проведення обчислювального експерименту з метою визначення ефективності використання захисних перешкод (габіонів) на території промислового майданчика.

Ключові слова: ризик ураження; динаміка руху уламка; габіон; математичне моделювання; термічне забруднення

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Надійшла до редколегії: 15.11.2024
Прийнята до друку: 19.03.2025

doi: https://doi.org/10.15802/stp2025/324155