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CONSTRUCTION AND DESIGN OF BUILDINGS AND STRUCTURES UNDER MARTIAL LAW. NEW CHALLENGES AND WAYS TO ADDRESS THEM

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Abstract

This paper is a result of the detailed analysis, carried out by a group of scientists at Dnipro University of Technology, of the circumstances and situation in the field

of construction, operation, and design of residential, communal, and industrial infrastructure facilities, which emerged after the full-scale invasion of Russia into Ukraine.

It formulates the new requirements that we devised for the construction of new, and reconstruction of existing buildings and structures, as well as for design and construction documentation.

The material presented in the current paper can be conditionally divided into 5 parts:

1. Legal and organizational foundations of the civil protection system.
2. Patterns of damage to civilian population in the course of military operations of various types and under various conditions.
3. Tendencies and patterns of destruction and damage to buildings and structures of various purposes and with various structural features during modern hostilities.
4. Modern principles, methods, and structures designed to protect civilian population in different countries.
5. Conclusions and recommendations regarding the calculation and design of cities, towns, buildings, and structures under conditions of the danger of conducting military operations.

Introduction

First, we shall consider the legal provisions based on which protection of the population (including civilians) of Ukraine should be carried out [1].

According to the Code of Civil Protection of Ukraine [2], every citizen of Ukraine has the right to protect his/her life and health from the consequences of accidents, disasters, fires, natural disasters, as well as for guarantees of ensuring the implementation of this right, including by sheltering in protective structures.

To ensure this right, Ukraine currently employs a Unified State System of Civil Protection, which has a rather complex and extensive organizational structure (Fig. 1). One of the important links in ensuring the safety of civilian population is the presence of protective structures. In the case of emergencies (technical, military, etc.), these structures provide civil protection of the population. It should also be noted that protective facilities are included in the civil defense system of Ukraine, as well as in the engineering service and the storage and shelter service.

In order to understand the need for certain properties that protective structures and shelters must possess under modern conditions, let us consider the data given in [3]. The authors analyzed the nature and type of population damage depending on the location

in relation to the front of hostilities (see also [4, 5, 6, 7, 8]). At the same time, the time range from World War I to the present time is considered (Table 1, Figs. 2 and 3).

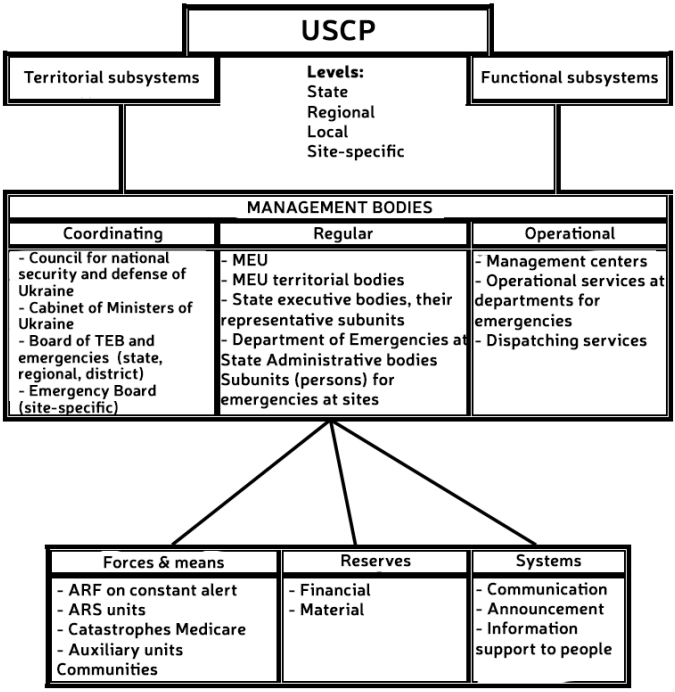

Fig. 1. Structure of the Unified State System of Civil Protection

Table 1

The percentage of injuries to the personnel of the armed forces and civilian population in the course of various conflicts

Damage type	The percentage of injuries to the personnel of the armed forces and civilian population during various conflicts									
	I		II		III		IV		V	
	Fatalities, %	Injured, %	Fatalities, %	Injured, %	Fatalities, %	Injured, %	Fatalities, %	Injured, %	Fatalities, %	Injured, %
1	35	42	50	32	49	40	67	34	-	-
2	65	58	12	46	41	43,2	18	51	-	-
3	-	-	38	22	10	16,8	15	16	5	5
4	-	-	-	-	-	-	-	-	-	95

Notes. The following designations are used in the table:1. In the first column of this table: *1* - bullet injuries; *2* - shrapnel damage; *3* - mine-explosive injuries; *4* – damage by powerful explosive devices with a large radius of action. I - losses during World War II (1941-1945); II - losses of the USSR during the Afghan war (1979-1989); III - losses of the Russian Federation during the first Chechen war (1994-1996); IV - losses of the Russian Federation during the second Chechen war (1999-2001); V - victims among civilians in Ukraine from February 24 to October 2, 2022 (according to the UN Human Rights Monitoring Mission in Ukraine).

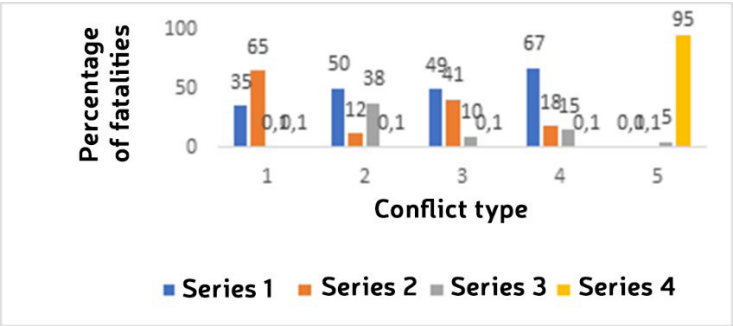

Fig. 2. The percentage of fatalities during military operations

Notes. In Fig. 1, the following notations are used: series; *1* – bullet injuries; series; *2* – the same, shrapnel; series *3* – the same, mines - explosive; *4* – damage by powerful explosive devices with a large radius of action. The following designations are used along the abscissa axis: *1* – losses during World War II (1941–1945); *2* – losses of the USSR during the Afghan war (1979–1989); *2* – losses of the Russian Federation during the first Chechen war (1994-1996); *4* - losses of the Russian Federation during the second Chechen war (1999-2001); *5* - victims among civilians in Ukraine from February 24 to October 2, 2022 (according to the UN Human Rights Monitoring Mission in Ukraine).

Analysis of the data given in Table 1 and Fig. 2 and 3 allowed us to conclude that there is a clear trend of increasing injuries to population by shrapnel (a consequence of artillery and mortar attacks), as well as injuries by powerful explosive devices with a large radius of action.

This trend holds both for fatalities (Fig. 2) and for injuries to people (Fig. 3).

It was concluded that modern protective structures should protect the population from shrapnel injuries, as well as from explosions of great force.

At the same time, it is understandable that protection against potential threats from nuclear, chemical, and bacteriological weapons should be provided for.

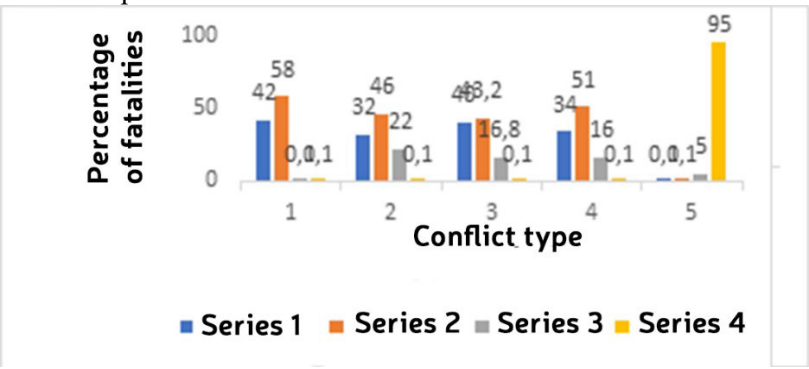

Fig. 3. Percentage of injuries during military operations. Notes: Series 1, 2, 3, and 4; numbers 1, 2, 3, 4, 5 along the abscissa axis refer to explanations in Fig. 2

Next, we shall consider modern trends in the destruction of buildings and structures of various purposes in the course of military operations, as well as damage to their various parts and structures on the example of such cities as Kyiv, Kharkiv, Odesa, Mariupol, Chernihiv, and Irpin [5, 6, 7, 8, 9 , 10].

In this case, the destruction and damage to buildings and structures in such cities as Kharkiv and Mariupol are the most characteristic.

This data is valuable from the point of view that the shelling and bombardment of these places was carried out using aviation, field and long-range artillery, rocket launchers and mortars.

In addition, during the street fighting in Mariupol, small arms were used very intensively.

The structure of damage and destruction of buildings and structures in the city of Kharkiv is shown in Fig. 4. Analysis of the presented data allowed us to conclude that windows are most often destroyed in the shelling zone. Next (in descending order) are roofs, walls, and porches.

Next, we shall analyze the regularities of the destruction in the city of Mariupol. According to the UN, up to 90 % of residential buildings and up to 60 % of private houses in the city were damaged or destroyed as a result of the fighting.

In addition, a clear tendency was revealed to launch rocket and artillery strikes on critical infrastructure objects, as well as on high-rise and other residential buildings, grocery stores, and objects of other civil infrastructure, in particular, a drama theater, maternity hospitals, etc.

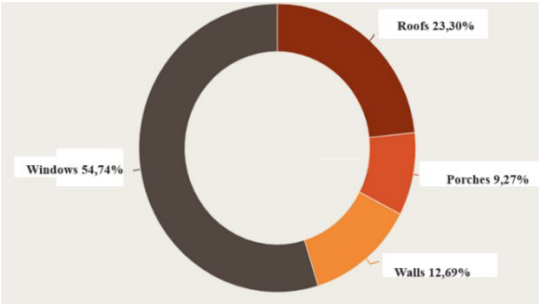

Fig. 4. Distribution of damage to various elements of buildings and structures in the city of Kharkiv as a result of military actions

At the same time, there were issues of damage to the population by fragments of explosive devices, fragments of glass and building structures.

Such damage took place both in the open space (on the streets and squares of the city) and inside the premises.

In addition, a huge problem was the need to liberate the civilian population hiding in the underground parts of buildings and structures, from under the debris of buildings and facilities destroyed during shelling (that is, rubble).

It also turned out to be a big surprise that a large part of the civilian population refused to move to premises safer than their apartments (i.e., bomb shelters, underground parking lots, subway stations, and other protective structures) after the announcement of the air raid alert. At the same time, the motivation behind this behavior turned out to be the following:

1. Health status of the elderly.
2. Long distance from the place of residence to protective structures.
3. The danger of being hit by fragments of explosive devices, buildings, structures, and other objects on the way from the place of residence to the protective structure.
4. The impossibility of evacuating people from under the rubble above protective structures located under residential buildings.
5. Insufficient thickness of ceilings above bomb shelters located in the basements of residential buildings and structures.

Fig. 5. Nature of damage and scheme of destruction of a panel building in the town of Borodyanka

Fig. 6. Nature of damage and scheme of destruction of a panel building in the city of Mariupol

In general, it was concluded that when designing structures for the protection of civilian population, it is necessary to ensure their protection from bullets, debris, and high-power explosions, and to ensure the possibility of evacuation from under the debris of structures of buildings and facilities destroyed during hostilities.

Next, we shall analyze the nature of damage to buildings and facilities with different structural implementation of load-bearing structures made of different materials [10].

The buildings were divided into the following groups:

- panel houses in the cities of Borodyanka and Mariupol with carrying or transverse load-bearing walls and floors made of precast reinforced concrete;
- brick buildings in the cities of Chasiv Yar, Kharkiv, and Chernihiv with carrying or transverse load-bearing walls and floors made of precast reinforced concrete;
- buildings in the cities of Kyiv and Odesa made of monolithic reinforced concrete with a spatial frame and a rigid reinforced concrete core (the functions of the core are performed by an elevator shaft).

Fig. 5 and 6 show photographs and diagrams of damage to panel buildings in Borodyanka (Fig. 5) and Mariupol (Fig. 6). These houses are built from reinforced concrete wall panels on which reinforced concrete floor slabs rest.

The destruction of these buildings includes the following common features:

- windows, doors, and partitions destroyed by the blast wave;
- traces of fires;
- avalanche-like destruction of load-bearing structures.

The essence of an avalanche-like destruction is that due to the action of weight from the structures of the destroyed upper floors, the load on the lower floor of the building increases. This leads to its destruction, due to which the load on the lower floor of the building increases. This process continues until the porch or house is completely destroyed. The procedures (more precisely, express methods) for determining the additional pressure on the inter-floor ceiling from the destroyed structures located above the floors and the method for determining the thickness of the ceiling above bomb shelters are given, respectively, in works [11] and [12].

In general, it was concluded that the main problems of panel buildings in the case of their damage by explosive devices are the destruction of windows, doors, partitions, fire, and avalanche-like destruction of supporting structures.

Fig. 7, 8, and 9 show photographs and diagrams of damage to brick buildings in the town of Chasiv-Yar (Fig. 7), in the city of Kharkiv (Fig. 8), and in the city of Chernihiv (Fig. 9). These houses have brick walls supported by reinforced concrete floor slabs.

On July 10, 2022, a brick dormitory building was destroyed in the town of Chasiv Yar in Donetsk region as a result of rocket fire. 4 rockets hit the house. 48 people died from the raids.

The photograph and the diagram in Fig. 7 demonstrate that the reinforced concrete inter-floor ceilings rest on brick load-bearing longitudinal walls. In this case, as a result of the destruction of the front wall of the building, the supports under the floor slabs were destroyed, as a result of which the building collapsed.

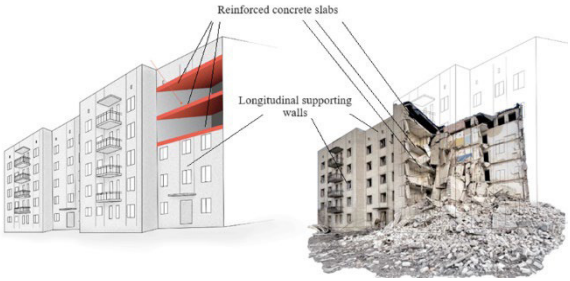

Fig. 7. Nature of damage and scheme of destruction of a brick building in the town of Chasiv-Yar

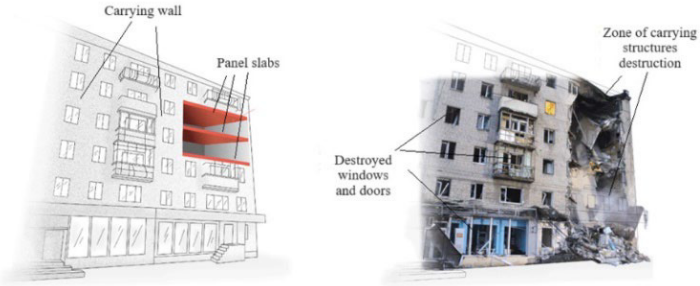

Fig. 8. Nature of damage and scheme of destruction of a brick building in the city of Kharkiv

In the city of Kharkiv, as a result of rocket fire on July 11, 2022, a brick building built in the 1960s in the historical center of Kharkiv was destroyed, and there were no casualties.

The photograph and the diagram in Fig. 8 demonstrate that the reinforced concrete inter-floor ceilings rest on brick load-bearing longitudinal walls.

In this case, as a result of the destruction of the front wall of the building, the supports under the floor slabs were destroyed, as a result of which the building collapsed. Thus, the nature and causes of the destruction in this case are completely identical to those discussed earlier (that is, the building in Chasiv Yar).

The "Ukraine" hotel building destroyed on the night of March 12, 2022, in Chernihiv is of interest in the sense that it was probably destroyed with the use of an Iskander missile (Fig. 9).

Also, in this case, there are the following differences from the cases considered above:

- reinforced concrete floor slabs are made of narrow slabs of the beam type;
- the walls of the building are much thicker than in the two considered cases.

Fig. 9. Nature of damage and the scheme of destruction of the brick building of the "Ukraine" hotel in the city of Chernihiv

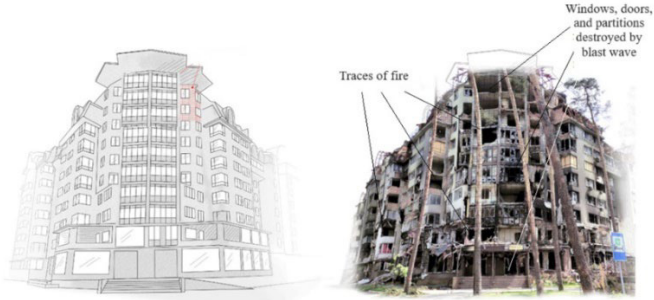

Fig. 10. Nature of damage and the scheme of destruction of the brick building of the "Ukraine" hotel in the city of Chernihiv

In this case, the destruction repeats the contour of the crater, as if the explosive device fell to the ground. One can see that, in this case, the rather strong and thick walls on the lower floors stayed put while the floor slabs were completely destroyed.

In general, it was concluded that the main problems of brick buildings in the case of their damage by explosive devices are the destruction of windows, doors, partitions, fire, avalanche-like destruction of load-bearing structures, and the destruction of slab supports and beams of floor coverings.

Next, we shall consider the characteristic damage to buildings that had been built according to the frame scheme.

The damage to the building in Irpin near Kyiv in the residential complex "Irpinski Lypky" (Fig. 10) is interesting from the point of view that this building was mostly damaged by fire, and not by explosions. In this case, there was damage to concrete (deterioration of properties, cracking, peeling, etc.), exposure and deterioration of the properties of reinforcement.

Fig. 11. Nature of damage to a multi-story building with a reinforced concrete frame

Such consequences of the fire are due to the fact that because of shelling it could not be extinguished within the standard time (1–2 hours). If the building had been equipped with an automatic fire extinguishing system, severe damage and destruction of its supporting structures would not have occurred.

In conclusion, we shall consider the structures of buildings, which are very promising from the point of view of living under wartime conditions.

These are buildings made of reinforced concrete, on a slab or pile foundation, with a monolithic frame and a monolithic stiffness core, the functions of which are performed by the elevator shaft and capital walls around the stairs.

First, let us consider a building located in the city of Kyiv near Zhuliany airport (Fig. 11), which was hit by a Russian missile on February 26 at the level of 17-20 floors. 2 people died, and 4 were injured. Fig. 11 shows that the damage to the building is local and there are no avalanche-like destructions of the floors above and below the place where the rocket hit.

Exactly the same picture was observed after a missile launched from a Tu-95 aircraft hit a high-rise building in Odesa on April 23 (Fig. 12). The rocket hit between the fourth and fifth floors, 8 people died, 18 were injured.

For comparison, the same figure (i.e., Fig. 12) shows the consequences of a rocket hitting a panel house in the city of Dnipro (it happened on January 14, 2023, at the level of the third floor), as a result of which 46 people died (11 of them were not identified and 11 were missing), and 80 people were injured [13].

Fig. 12. Nature of damage to multi-story buildings: panel (left image) and reinforced concrete frame (right image)

Fig.12 demonstrates the difference in the destruction of panel and frame buildings under approximately the same conditions of their damage.

In addition to the fact that the destruction of a panel building is much greater than that of a frame house, about seven times as many people died and went missing inside it, and four times as many people were injured. This clearly shows the significant advantages of buildings made of monolithic concrete and spatial frames over panel ones.

Also, the images shown in Figs. 5-12 testify to the following:

1. The most vulnerable are the buildings, the above-ground part of which is built from factory-ready reinforced concrete slabs, and the least vulnerable are the buildings with a monolithic spatial frame and a rigid core.

2. In all considered cases, the damage to the underground part of the buildings was minimal.

Considering the second conclusion, the data reported in [14] regarding the relationship between the excess pressure at the front of the air blast wave and the pressure in the soil layer caused by the explosion are of interest (Fig. 13).

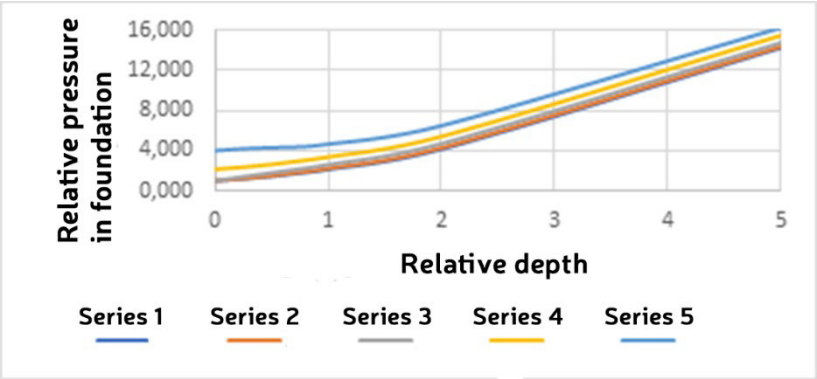

Fig. 13. Relative pressure p_0 at relative depth z_0 and relative distance from the explosion site r_0. Notes: the following designations are used: series 1 - r_0=0;; series 2 - r_0=0,5; series 3 - r_0=1;; series 4 - r_0=1,5; series 5 - r_0=1,5

2. The relative parameters (that is, pressure, depth, and distance from the site of explosion on the surface of the base) should be determined according to formulas (1).

The solution was derived in a cylindrical coordinate system for dimensionless pressure, depth, and distance from the explosion site. In this case, the following relationship holds between the relative, actual coordinates, and the energy of the explosion

$$r_0 = \frac{r}{\sqrt[3]{\lambda \cdot Q}}; \quad z_0 = \frac{z}{\sqrt[3]{\lambda \cdot Q}}; \qquad \overline{P}(r_0, z_0) = \frac{P(1,0)}{P(r_0, z_0)}. \tag{1}$$

The following designations are used in the formula: r and z, accordingly, are the actual horizontal distance from the center of the explosion and the depth at which the actual pressure in the soil base is determined; $P(r_0,z_0)$=1 if the explosion occurred in the air and λ=2 if the explosion occurred on the surface of the earth; Q - explosion energy in calories.

Analysis of data shown in Fig. 13 allowed us to conclude that the location of civil structures below the soil surface makes it possible to significantly (many times) reduce the destructive energy of blast waves. This conclusion is not new. It is confirmed by the entire

previous practice of building fortification facilities and civil defense structures [15, 16].

Fig. 14. The world's largest Doomsday community has built an entire city with 575 underground bunkers. The photograph on the left is the general view of the town from the side of the soil surface, and on the right − the interior

Fig. 15. Individual bomb shelter [18]

Fig. 14, 15, and 16 show options for underground structures for the protection of civilian population, built in different countries and under different conditions.

In particular, Fig. 14 displays a photograph of an underground city with 575 bunkers with arched supporting structures [17]. A characteristic feature of the town is the increased comfort of residential premises. Also worthy of attention are the latest Ukrainian advancements of factory-ready individual shelters (Fig. 15), which perform the same functions as the bunkers of the "Doomsday" community [18]. These structures have an advantage in speed and manufacturability of construction (a minimum of operations under

field conditions). In this case, in our opinion, the issues of thermal insulation, corrosion, location in depth, and protection against direct impact on these buildings need further clarification [12, 14].

Fig. 16. Example of the conversion of industrial facilities into structures for the protection of civilian population. Cozy apartments in an abandoned mine [19]

It is also of interest to convert abandoned civil and military facilities into structures for the protection of civilian population (Fig. 16).

In this case, the following goals were achieved:

- disposal of an abandoned building (thus saving funds for its destruction);
- reduction of costs for maintenance of abandoned structures in proper condition;
- construction of new comfortable housing;
- construction of new civil defense facilities.

Here, a clear trend of combining different functions in structures intended for the protection of civilian population is observed [20-32]. This is due to the high cost of construction and operation of purely civil protection facilities. In this case, the provision of several functions to protective structures makes it possible to significantly reduce the costs of their operation and pay off the costs of their construction. Successful examples of such dual use of civil defense facilities are subways, underground parking lots, shopping centers, technical and storage facilities, etc.

Thus, the data presented in this part of the paper allow us to formulate the following conclusions:

1. The structures intended for the protection of civilian population should be located below the level of soil surface (that is, underground).

2. The combination of various functions in structures intended for the protection of civilian population makes it possible to significantly reduce the costs of their operation and pay off the costs of their construction.

In some cases, the construction of underground civil defense structures is either impossible or impractical. This is due to the following reasons:

1. High level of underground water (in this case, there are problems of their constant pumping or complete sealing of the structure of the building, mold, flood safety in case of damage to the enclosing structures of the storage, etc.).

2. A long distance or a dangerous path from the structure of civil protection to the place of people residence.

3. Impossibility or reluctance of people to leave homes during an air raid period.

Considering the issues discussed, the experience of using the so-called mamad and mamak in Israel deserves attention [33, 34, 35]. The difference in these definitions is that mamad (abbreviation of merhav mugan dirati - "protected space of the apartment") is a fortified room in a private apartment, while mamak is a fortified room in public facilities. The difference between mamaks and our bomb shelters in the traditional sense is that mamaks are placed on each floor.

According to the requirements given in [35], mamads should have the following minimum properties:

- the area of mamad must be at least 9 square m;
- ceiling height – 2.5 m;
- the walls of mamad should be reinforced concrete, 25-30 cm thick or more;
- mamad must have metal hermetic doors that can withstand the blast wave;
- mamad must be equipped with filters to protect against attacks using chemical, biological, and nuclear weapons (in the latter case, radioactive dust is meant).

Of interest is the experience accumulated at Dnipro University of Technology in the course of master's theses in redesigning residential buildings into houses with mamads, Fig. 17.

In this case, the following goals are achieved by adding mamad (or mamak) to the existing building:

1. In this way, the safety of the people living in the house increases.

2. The living space increases and, thus, its value increases.

In our opinion, it is expedient to add monolithic concrete mamads to all existing panel and brick buildings.

Building before reconstruction Building after reconstruction

Fig. 17. Schematic of mamad attachment to the existing building

Conclusions

1. According to the Code of Civil Protection of Ukraine, every citizen of Ukraine has the right to protect his/her life and health from the consequences of accidents, disasters, fires, natural disasters, and for guarantees to ensure the implementation of this right, including by sheltering in protective structures. To ensure this right, the Unified State System of Civil Protection currently operates in Ukraine.

2. One of the important links in ensuring the security of civilian population is the presence of protective structures that are included in the civil defense system of Ukraine, as well as in the engineering service and the storage and shelter service.

3. There is a clear trend of growth (compared to previous conflicts) of injuries to people by shrapnel (this is a consequence of artillery and mortar attacks), as well as injuries by powerful explosive devices with a large radius of action and high explosive energy. Injuries to the population by fragments of explosive devices, fragments of glass and building structures took place both in the open space (on the streets and squares of the city) and inside the premises.

In this case, the largest number of fatal injuries to civilian population occurs in the places of its greatest concentration (the most characteristic example is the bombing of the Mariupol Drama Theater [9]).

4. A huge problem is the need to liberate civilian population hiding in the underground parts of buildings and structures, from under the debris of buildings and structures destroyed during shelling (that is, rubble).

5. There is also the issue of the refusal of a large part of civilian population to move to premises that are safer than their apartments (that is, to bomb shelters, underground parking lots, subway stations, and other protective structures) after the announcement of an air raid alert. In this case, according to the population survey, the motivation behind such unusual behavior turned out to be the following factors:

5.1. Health condition of the elderly.

5.2. A long distance from the place of residence to protective structures.

5.3. The danger of being hit by fragments of explosive devices, buildings, structures, and other objects on the way from the place of residence to the protective structure.

5.4. The impossibility of evacuating people from under the rubble above protective structures located under residential buildings.

5.5. Insufficient thickness of ceilings above bomb shelters located in the basements of residential buildings and structures (this reduces the protective properties of bomb shelters).

6. In the zone of shelling, windows are most often destroyed. Next (in descending order) are roofs, walls, and porches. Also, in places of explosions of concentrated charges of high power, entire entrances and buildings are destroyed. In this case, the underground part of buildings and structures is the most protected from damage.

7. Under wartime conditions, the most dangerous are panel buildings, and the most promising from the point of view of safety are buildings built from monolithic reinforced concrete and having the following design features:

- slab or pile foundation;
- reinforced concrete spatial frame;
- reinforced concrete core of rigidity.

Brick buildings and buildings with other structural schemes occupy an intermediate position between panel and frame buildings from the point of view of safety.

8. More modern buildings give more chances of salvation for more people. However, they do not guarantee complete security. This should be kept in mind when choosing a shelter during an air raid and a possible missile attack.

9. An important factor in improving the quality of protection of civilian population, civil defense facilities, and the national economy (in particular, trade, critical infrastructure, and industry) is their location below the soil surface level (that is, underground).

10. There is a positive world experience of using ordinary buildings and facilities of high-security zones, the so-called mamad and mamak.

This method of protecting civilian population under the conditions of hostilities has an advantage over the ones discussed above in the close proximity of the underground water to the soil surface and the short flight time of the means of destruction to the object in which civilian population is located.

The disadvantage of such structures is the possibility of defeat by concentrated explosive devices of high power.

11. There is also the problem of using modern construction standards in the design, construction, and reconstruction of buildings and facilities, taking into account the situation that arose as a result of the armed attack of the Russian Federation on Ukraine. The essence of this problem is the fact that the state building regulations currently in force on the territory of Ukraine (i.e., SBR) do not include strict requirements for the construction and operation of structures intended for the protection of people during military operations.

Also, the issue of dual use of civil protection facilities, for example, additionally as production, trade, warehouse, technical, and other premises, has not been worked out in SBR.

The following recommendations and suggestions follow from the above conclusions:

1. To justify the legal basis of actions during the design, construction, reconstruction, and operation of structures, the data given in points 1 and 2 of the conclusions should be used.

2. The planning of settlements must meet the following requirements:

- maximum separation of residential and industrial facilities in the plan (this could reduce the destructive effect of high-power explosions with a high concentration of explosives);
- the height of residential buildings, in the basements of which shelters intended for the protection of civilian population are located, and the distances between them should allow trouble-free placement of ways for emergency exits from shelters in accordance with SBR requirements;
- transport highways should have above-ground (bridges) and underground (tunnels) sections, which, in the case of danger after detonation, should act as obstacles for enemy equipment;
- the height of buildings and structures should be limited to 4-5 above-ground floors (this is the experience of Israel), while the number of underground floors can be as large as desired;
- new small architectural forms should be introduced into design practice - structures designed to protect civilian population in places of their concentration (public transport stops, platforms in front of shopping facilities, etc.).

3. Premises for the protection of civilian population, shopping centers, objects of critical infrastructure, especially important productions, and other facilities important for the national economy of Ukraine should be placed below the level of soil surface. This will provide them with additional (compared to their above-ground placement) protection.

4. New buildings and structures must be made mainly of monolithic reinforced concrete and have the following structure:

- slab or pile foundation;
- reinforced concrete spatial frame;

- reinforced concrete core of rigidity;

- underground parking and (or) premises for the protection of civilian population with a monolithic reinforced concrete floor above them with a thickness of at least 1000 mm.

In this case, the following should be placed inside the monolithic reinforced concrete core:

- elevator shaft;

- explosion-proof staircases connecting adjacent floors;

- comfortable rooms with reinforced walls and ceilings, designed to protect people from the effects of blast waves, debris, chemical weapons, fires, etc. (analogs of Israeli mamad and mamak).

5. During the construction, design of new, and reconstruction of old structures, the following basic rules should be observed:

5.1. Each of the residential buildings must have a civil defense facility (i.e., shelter).

5.1.1. This structure, if possible, must be underground. It should create comfortable conditions for the long-term living of people.

5.1.2. Each of the civil protection facilities must have several emergency exits. The outer ends of these exits must be located in such a way and at such a distance that guarantees the impossibility of their being filled with debris from nearby destroyed buildings and structures.

5.1.3. The monolithic reinforced concrete floor over shelters for the protection of civilian population must withstand the additional load from the weight of the destroyed floors and the action of the explosion of the estimated charge. Its structural thickness should be at least 1000 mm.

5.2. A very promising direction is the arrangement of protected premises on each floor in buildings and structures. This practice has become widespread in Israel. There, such premises are called mamad and mamak [33, 34].

5.3. Windows should be made either completely protected from the blast wave, or from such materials that cause minimal damage when destroyed (film, tempered glass, etc.).

5.4. Roofs of buildings should be made in a reinforced version, or in such a way that they can be quickly restored with minimal costs (a combined version is also promising).

5.5. The walls of buildings should also be made in a reinforced version, such that they can withstand the pressure of the blast wave and damage from the fragments of the blast wave.

5.6. Entrances and exits from destroyed buildings and structures (in particular, entrances) are also a weak point of pre-war buildings. In our opinion, the solution to this problem is the presence of one or more emergency exits, as well as inter-floor stairs protected from fragments of explosive devices and bullets.

6. The protective properties of existing buildings and structures should be increased using the following methods:

6.1. By means of reconstruction of already existing basements (increasing the comfort of staying in them, arranging additional emergency exits, strengthening the floors above the basement, etc.).

6.2. By adding to existing buildings and structures premises with reinforced structures that withstand the impact of shock waves, fragments of explosive devices and fragments of buildings and structures, fires, chemical attacks, etc. (there is a positive experience of using such structures in Israel, where they are called mamad or mamak).

6.3. By expanding underground communications in such a way that it was possible to use them to leave basements and shelters under rubble. This allows one to achieve the following goals:

- to increase the safety of people in densely built-up areas;
- to improve the operating conditions of tunnels in which communications are laid.

7. When designing and reconstructing buildings and structures, it is imperative to combine several functions with structures intended to protect the civilian population. In this case, there is a significant improvement in payback and a reduction in the cost of operating such facilities. Successful examples of such a combination are the use of subway stations and underground passages, which house commercial enterprises that are operated as:

- transport arteries;
- trade enterprises;
- structures intended for the protection of civilian population.

8. It is necessary to adapt the state building regulations (SBR) currently in force on the territory of Ukraine to modern conditions.

This is achieved by adding relevant sections or amendments to the currently valid documents.

Examples:

- SBR B.1.2-2:2006 "Loads and impacts" should be supplemented with a section that allows one to calculate the load from the explosive shock wave, from the weight of structures destroyed by the explosion, etc.;

- SBR B.2.2-9:2018 "Buildings and structures" should be supplemented with sections "underground and above-ground facilities intended for the protection of civilian population", "design of additional emergency exits", etc.

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