UDC 624.94.012.45

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Analysis of foreign experience in the use of personal shelters

The research is devoted to the study and synthesis of national and foreign experience in providing short-term protection of civilians from various threats of natural, technogenic and anthropogenic origin by constructing various shelters. A general classification of personal shelters has been developed.

Inroducrion

Protective structures of civil defense help to protect people from various threats (biological, chemical, radioactive). There are requirements according to which they are built and supplied with the necessary: air, a supply of food, water for drinking and hygiene.

The protective structure is a specific shelter for the protection of the population from ammunition, radiation, nuclear and radioactive weapons. Vaults will be able to protect people from biological weapons, floods, chemical weapons, radiation, debris.

Every citizen should be aware of protective premises, their types, purposes and equipment in order to protect themselves and their loved ones in the event of a possible threat.

The use of civil defense facilities is one of the main ways of protecting people. Their most widespread use was during WW2, which helped save the lives of many.

According to Ukranian building codes [1-3] the following protective objects are distinguished:

- protective structure of civil defense – an engineering structure designed to protect the population from exposure to dangerous factors that arise as a result of emergency situations, hostilities or acts of terrorism;
- shelter – A hermetically sealed structure is designed to provide protection to individuals by creating exclusionary conditions for a specific duration, safeguarding them from the harmful effects of emergency situations, military conflicts, and terrorist attacks.
- anti-radiation shelter – a non-hermetic structure for the protection of people, in which conditions are created that exclude influence on them of ionizing radiation in case of radioactive contamination of the area.

Experience of Israel

As for Israel's experience, the country, which has been living in a state of military conflict for a long time, solved the problem of shelters a long time ago.

The term "safe room," which refers to a fortified or protected space, has become an indispensable part of the Israeli household vocabulary. Its origin dates back to the 1990 Gulf War when individuals had to rapidly relocate to a secure area, often in the middle of the night, where they would wear gas masks and wait for the Scud missiles fired from Iraq to pass. This space was known as a "sealed room" and its windows and doors were covered with plastic sheeting to safeguard against the potential use of chemical weapons.

Over the following two decades, with the looming threat of chemical warfare, the Home Front Command opted to prioritize elevated protected spaces over basement bomb shelters or sealed rooms. As per the new regulations, every new building was mandated to have a safe room, known as mamad (an acronym for merhav mugan dirati), constructed from reinforced concrete, fitted with a sealed, heavy window, and a steel vault-like door, capable of shielding occupants from rocket blasts.

Recent residential constructions feature either mamaks (merhav mugan komati) safe rooms for each floor or mamads built within each apartment, often stacked atop one another to create a central core of safe rooms in the building. In older buildings, owners can opt to create fortified rooms by reinforcing a standard room with 12 centimeters of concrete, and installing a specialized steel door, window, and a reinforced ceiling. A more affordable alternative, which meets government standards, is a steel cage within an existing room, covered with another layer of cement. For those without a safe room or bomb shelter, the stairwell, typically made of concrete and encircled by supporting pillars that hold the building up, is often deemed the safest location in the building.

The protected space was previously limited to a mere five square meters and was typically repurposed as a storage room or laundry room. However, the minimum size has now been increased to nine meters. According to architect Netanel Chaziza, most individuals utilize it as a workspace or bedroom.

Initially, safe rooms were constructed from concrete blocks. However, in recent years, they are built from 20 centimeters of high-end concrete, a more robust and denser material than conventional concrete, and feature an inner wall of reinforced steel.

Types of shelters

The experience of different countries shows that there is a wide variety of shelters and refuges that still do not have a clear international or even national classification. Taking into account the latest developments and research in the field of design and planning solutions for shelters [6-8] and modern construction materials [4, 5], we propose a universal classification (Tab. 1).

Personal Shelters								
By purpose	**By manufacturing method**	**By capacity and size**	**By type and level of protection**	**By material of manufacture**	**By placement method**		**By the number of levels**	**By access time**
special	monolithic	(S) small (1-3 p.)	from natural disasters (earthquakes, storms, tornadoes, floods...)	metal	Mobile / Stationary		single-level	extremely accessible (up to 1 min)
multifunctional	assembled	(M) medium (4-7 p.)	from fires	reinforced concrete	*Freestanding*	*Integrated (attached)*	multilevel	close to accessible (1-5 min)
		(L) large (8-14 p.)	from rocket and artillery fire	steel and reinforced concrete	underground	basement		accessible (5-10 min)
		(XL) extremely large (over 14 p.)	from direct hits by small arms	composite	surface	indoor		remote (10-30 min)
			from radiation and bacteriological impacts	polymeric	overground	inter-room		inaccessible (more than 30 minutes)
				combined		nterfloor		

Fig. 1. Types of personal shelters

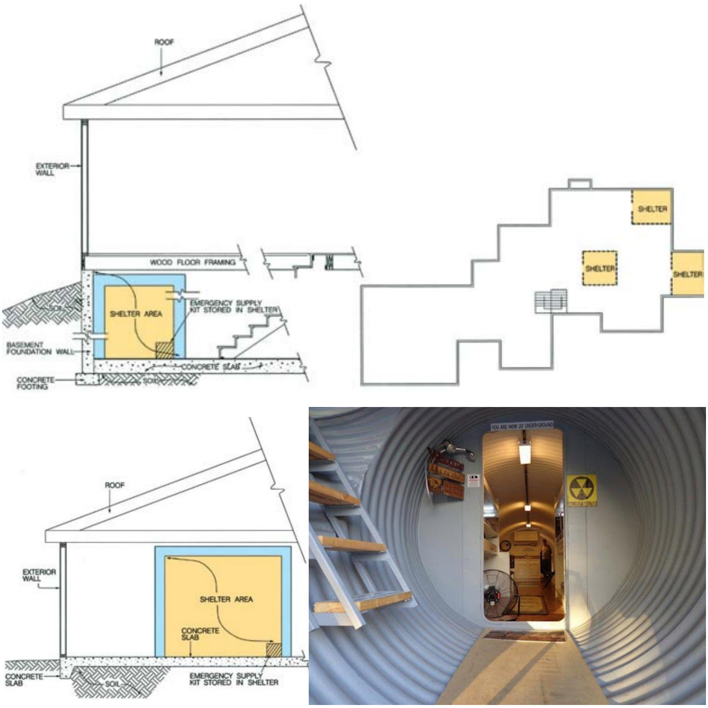

Fig. 2. Example of the personal shelter location in a building

Ballistic-resistantance

Designing for ballistic resistance involves two main strategies: preventing sightlines to conceal the occupants and using materials that can resist ballistic threats to reduce their effectiveness. To limit exposure, the safe room should be located as far inside the facility as possible and doorways should be placed in a way that does not provide a direct line of sight. The walls must be constructed with appropriate thickness and material, including reinforced concrete, masonry, mild steel plate, or composite materials, to provide the necessary level of resistance against ballistic threats. The thickness of these materials depends on the level of resistance required. For high-level protection, for instance, 6.5 inches of reinforced concrete, 8 inches of grouted concrete masonry unit or brick, 1 inch mild steel plate, or ¾ inch armor steel plate may be used. A ½-inch thick bullet-resistant fiberglass layer may be sufficient for medium-level protection.

For a high level of protection, bullet-resistant doors are necessary, although hollow steel or steel clad doors with pressed steel frames can be used with an appropriate concealed entryway. Ballistic-resistant window assemblies typically contain multiple layers of laminated glass or polycarbonate materials and steel frames. These assemblies tend to be heavy and costly, so their number and size should be minimized. Lastly, the roof structures should use materials similar to the ballistic-resistant wall assemblies. Ratings of bullet-resisting materials are presented in table 1.

Table 1.

Types of personal shelters

Rating	Ammunition	Grain	Minimum Velocity (fps)
Level 1	9mm full metal copper jacket with lead core	124	1.185
Level 2	.357 Magnum jacketed lead soft point	158	1.250
Level 3	.44 Magnum lead semi-wadcutter gas checked	240	1.350
Level 4	.30 caliber rifle lead core soft point	180	2.540
Level 5	7.62 mm rifle lead core full metal copper jacket, military ball	150	2.750
Level 6	9 mm Full metal copper jacket with lead core	124	1.400
Level 7	5.56 mm rifle full metal copper jacket with lead core	55	3.080
Level 8	7.62 mm rifle lead core full metal copper jacket, military ball	150	2.750

Determination of excess pressure in the front of the shock wave and effective duration in the explosion of hydrocarbon-air mixtures

In the explosion of a hydrocarbon-air mixture (HAM), there are two zones of action: a detonation wave within the limits of the cloud of hydrocarbons and an air shock wave outside the clouds of hydrocarbons. Parameters of the explosion of the hydrocarbon-air mixture (pressure in the front and effective time shock wave action) depend from the distance to the center of the explosion and from the composition of the hydrocarbon-air mixture. Cited the formulas below correspond to the averaged physical and mechanical and energy characteristics of a stoichiometric mixture with air hydrocarbon gases type C_mH_n (acetylene, methane, ethane, propane, butane, pentane, ethylene, propylene, butylene) and an idealized scheme of explosion (detonation) of a hemispheric cloud of hydrocarbons with explosion initiation at its center.

Hydrocarbon-air mixture cloud area

The initial radius of the cloud of the hydrocarbons, m, is equal to

$$r_0 = 18{,}5\sqrt[3]{Q}, \qquad (1)$$

where Q – amount of hydrocarbon gases in the fuel-air mixture, determined by the formula $Q = K_H Q_H$,

where Q_H – amount of liquefied hydrocarbon gases in the storage tanks before the explosion, tc; K_H – coefficient of transition of the liquefied product into hydrocarbon-air mixture, the value of which is taken equal to K_H= 0,6.

In the zone of the cloud, a detonation wave acts, the overpressure in the front of which is assumed constant within the limits of the hydrocarbon cloud and equal to $\Delta P_g =$

1,7 MPa. The effective action time ɵ of the detonation wave, s, is determined by the formula:

$$ɵ = 0.37 * 10^{-3} r_0 \left(\frac{r}{r_0}\right)^{0.27} \quad at\ 0.3 \leq \frac{r}{r_0} \leq 1 \qquad (2)$$

where r_0 and r are the initial radius of the HAM cloud and the distance to the explosion center, m

When the detonation wave is reflected from the obstacle, when the structure is located perpendicular to the direction of propagation of the detonation wave, the pressure on the obstacle exceeds the pressure at the detonation wave front by about 2.5 times, and the effective operating time of the excess pressure of reflection is about 1.25 times less than that calculated from the formula.

Conclusions

Considering the current global geopolitical trends and the war on the territory of Ukraine, further research on personal shelters is extremely relevant. The study and generalization of international experience in planning, designing, and installing various shelters should be conducted taking into account the latest developments in high-strength steel and reinforced concrete and composite structures. Further improvement of the classification of shelters will unify their most common models and allow for much more efficient exchange of best practices between scientists around the world.

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