DOI: 10.5604/01.3001.0053.9620
Volume 120 • Issue 1 • September 2023
Journal of Achievements in Materials and Manufacturing Engineering
International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Material and construction solutions in the construction of civil defence shelters

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ABSTRACT

Purpose: An analysis is presented of the use of material and construction solutions used in construction, mainly residential, for the construction of OC (civil defence) shelters.

Design/methodology/approach: The article presents procedures for designing reinforced concrete structures that make it possible to properly determine the load capacity of critical sections. In the present work, a study of the deformation stability of a zone of reinforced concrete sections that is subjected to compression is used. Computational methods based on Drucker's postulate were used to solve the problem. The proposed approach enables the determination of the values of ultimate and failure strains based on the analysis of the loading path of a reinforced concrete section.

Findings: Generally, shelters built into residential buildings are analysed, intended to be constructed in the rooms of the basement floor. A reduced need for ancillary space, the basement room, is observed. Garage functions are located on the basement floor. The plan contours of the basement are often larger than those of the ground floor. It is possible to design a shelter for the residents of the building, which ensures the greatest efficiency in its use. It is desirable to maintain uniform material and construction solutions while maintaining technological and organisational solutions during the erection of the entire building.

Research limitations/implications: The paper indicates the possibility of using some of the material and structural solutions of the housing construction in the realisation of OC shelters built into the basement floor. The construction of free-standing shelters was not analysed separately, but the proposals presented in the paper can also be applied to the type of OC shelters. Some results of the analysis of the adaptation of material and structural solutions of the housing construction to the needs of OC shelters construction will be presented during the symposium.

Practical implications: It is advisable to develop models for the construction of OC shelters using contemporary technologies used in the construction industry.

Originality/value: Useful tool can be the proposed scheme for improving activities based on the EFQM model.

Keywords: Human behaviour, Safety and health protection, Higher education school and scientific institutes, Quality, Education

Reference to this paper should be given in the following way:
A. Baryłka, M. Szota, Material and construction solutions in the construction of civil defence shelters, Journal of Achievements in Materials and Manufacturing Engineering 120/1 (2023) 5-9.
DOI: https://doi.org/10.5604/01.3001.0053.9620

PROPERTIES

1. Introduction

The primary purpose to be fulfilled by civil defence shelter structures is the protection of persons and property in emergencies, i.e., the occurrence of threats of war and disasters of environmental scope. The civil defence concept does not envisage capturing all the factors that are associated with the hazards posed by warfare. The occurrence of overpressure caused by explosions of conventional or nuclear means of destruction and the impact of secondary factors, i.e., fire, radioactive fallout, or clutter, are considered [1-6]. Environmental disasters are mainly fires, and the spread of toxic industrial agents used locally or transported through or over an area.

If the protective structure is a shelter, it is required to have the capacity to perform protective functions under dynamic mechanical actions and to effectively attenuate penetrating radiation from radioactive fallout while maintaining its airtightness. OC shelters are mainly located in highly urbanised areas. They can be designed for varying numbers of people, starting with as few as a few people.

The functional layout of the shelter reflects the protection concept in terms of solutions.

- local, concerning the entry system, spare exits, stockpiling air, water and energy supply, disposal or storage of waste and sanitary sewage;
- global, including operating regimes (e.g., full isolation), general operating concepts, communication with the outside world.

The structural solution of the shelter must ensure adequate resistance to mechanical influences and air tightness. The installation and quartermaster equipment ensures operational efficiency. Those issues must be resolved at the design stage of the facility for the assumed resistance and equipment standard.

As a rule of thumb, OC shelters in peacetime may be used as facilities or parts for purposes other than protection. It reduces the costs of implementing such facilities and maintaining them. Some equipment elements may then be made not before the facility is put into operation but before the expected danger occurs. Provision should then be made to eliminate the non-shelter function.

OC shelters can be designed and constructed in advance as free-standing structures or parts of structures built for other purposes.

Other protective functions are attributed to the second group of protective structures, which are hides. They are only required to provide effective insulation against poisonous agents and penetrating radiation. It is generally considered that hiding places can be set up ad hoc in existing buildings or structures. There is generally no emphasis on the need for them to be prepared in advance in terms of their function or at the construction stage of the facility and for appropriate procedures to be established for adapting the facility to its protective function during the period of expected danger and its subsequent use as a hiding place. Instead, it is considered necessary to adequately prepare and arrange them in the period before the threat. However, the presented view of such a procedure is debatable. It is because it is difficult to properly implement the furnishing of concealments under ad hoc conditions. The necessity to plan them functionally at the stage of designing the facility and to prepare appropriate procedures to be implemented in the period of danger, as well as to make the user of the facility aware of possible future protective tasks in advance, should not be deferred to the period of danger. The view that hiding places should only be envisaged for less urbanised areas is also highly debatable.

The paper will consider the design options for built-in and free-standing OC shelters using contemporary materials and construction solutions for residential buildings. The essential analyses will refer to basement shelters in residential buildings. We will not analyse the problem of arranging shelters.

2. Direct and secondary impacts

The direct impact on the above-ground part of the building that houses the OC shelter is assumed to be transmitted from the external environment as an airborne overpressure wave with a strong discontinuity front of $p\Delta_m$. Its effect is global. It acts on the windward wall of the building generating a rebound effect which is revealed by a significant increase in the intensity of the overpressure at the wavefront. It envelops the other walls. In addition, it also induces a pressure wave propagating in the ground medium, which causes a load on the underground part of the building. Unlike an air wave, a pressure wave in the ground has a fuzzy front. The mechanism of the wave reflection phenomenon and its interaction with the underground part of the building is different. In general, the effects of the dynamic action of a ground pressure wave on the foundation walls of a building are much milder than that of an airwave on the above-ground part. Such an intensity of overpressure at the air wavefront is assumed $p\Delta_m$, which conditions the destruction of the above-ground part of the building. The destruction results in the cluttering of the underground part. It occurs dynamically. Massive impacts from falling structural elements or heavy objects of building equipment are possible.

It can be seen from the above that the sheltered enclosure will be subjected to different loads. A ground pressure wave will load the outer foundation walls. The outer floor of the shelter will be loaded by an air shock wave and, at the same time, by debris. The accumulation of debris will also extend to the immediate surroundings of the building and cause additional pressure on the external basement walls. In some cases, it may be necessary to analyse the occurrence of the downward pressure effect on the ground slab and, especially in its absence, on the basement floor with its subsoil.

In the case of frame buildings with lightweight curtain walling, it is possible to 'rewind' – to remove infill, built-in products and functionally useful equipment.

In addition to these mechanical loads, the impact of high temperatures caused by external fires should be considered. They should not lead to excessive heating of the external enclosure components.

The literature shows that an airborne overpressure wave with different values of maximum overpressure $p\Delta_{m.}$ at the front of an incidental airburst wave causes damage to a building to varying degrees. An overpressure of 0.02 MPa is reported to cause damage to reinforced concrete and concrete walls of typical building thicknesses. Consequently, the load-bearing structure of the building is affected. The floors above the basement may be partially destroyed. Destruction of the above-ground part of the building can occur at overpressures of 0.02-0.03 MPa, [7]. For such a reason, it can be considered that the overpressure $p\Delta_m = 0.02$ MPa is the minimum requirement for OC shelter resistance [1]. The value of 0.035 MPa was assumed in previous periods [2,6].

3. Basic loads and structural design

The basic loads for which the building structure must be designed are determined by its function, the shape of its mass and its location in relation to climatic zones. The introduction of a shelter function in the basement part of the building requires the consideration of appropriate basic load configurations for an OC shelter. In principle, the loading of the shelter structure should be analysed in two loading stages [1,2,7].

Stage I is the loading situation during the action of an air wave of overpressure of an intensity destructive, by design, to the above-ground part of the building. The overpressure, amplified by the effects of reflections on the partitions and embankments around the building, may directly affect some structural elements of the shelter, access structures, and shelter doors. The overpressure also affects the ceiling covering the shelter rooms after the wave has broken into the building through the openings in the external walls. At the same time, the destructive aboveground part of the building creates a debris load that transfers itself to the ceiling covering the shelter and its immediate surroundings. There is no experimental information on the dynamics of the load or the effect of dynamic excitation of the elements of the enclosure structure caused by the action of the overpressure wave.

It is further noted that there is a need to analyse the effects of incidental mass impacts from either rigid structural elements or heavy equipment. Crumbling and impact are secondary actions of a typically dynamic nature. It should only be noted that crushing is a non-vanishing load. Generally, the qualification of loads according to duration should be considered a short-term load, bearing in mind that it may act on a plastically deformed structure. The static action of the crumbling, together with the thermal effect of the resulting external fire, forms stage II loading of the shelter enclosure.

In the design of a shelter structure, the correct design result can be achieved if we dimension the critical cross-sections of the floor load-bearing elements to the internal forces determined from the static calculations for an appropriately selected static equivalent load from the crumbling [3-5]. The minimum value of the load is given, $p \geq 20$ KPa. In foreign regulations, its intensity is proposed to be determined depending on the number of storeys of the above-ground part of the building and the type of its load-bearing structure. It is suggested to take the substitute load of the external floor of the shelter depending on the type of load-bearing structure of the building. In the case of buildings with load-bearing walls with *n* overground storeys

$$20 \text{ KPa} \leq \Delta\, p_r = [10 + 5\,(n - 2)] \leq 50 \text{ Kpa}, \qquad (1)$$

for frame buildings

$$20 \text{ KPa} \leq \Delta\, p_r = [10 + 2.5\,(n - 2)] \leq 25 \text{ KPa}. \qquad (2)$$

In addition, the ceiling must withstand the impact of a rigid mass, which is effectively protected by a suitable damping layer.

In stage II of the shelter load, the global impact on the foundations of the destroyed building decreases, but the load on the adjacent ground surface increases. Thus, the horizontal pressure e_1 transmitted to the walls of the outer enclosure increases. If the wall of the sheltered enclosure is not an internal wall of the basement, the situation of it being buried by debris causing a pressure e_2 is considered. Those pressures can be assumed to be uniformly distributed over the height of the basement wall. Their values are equal to

$$e_1 = \xi_b \Delta\, p_r,$$
$$e_2 = 10 \text{ KPa}, \qquad (3)$$

where ξ_b – lateral thrust coefficient. In typical foundation situations in dry sands ξ_b = 0.6-0.7, in clays ξ_b = 0.4-0.5; and dry gravels ξ_b = 0.2-0.3. Such data are presented in more detail in [7].

4. Characteristics of material and construction solutions

The design of an OC shelter in the underground part of a residential building requires adopting such a material and construction solution to ensure that mechanical resistance requirements are met, that residual radiation is attenuated and that the shelter structure is protected against excessive heating from fire. Following the principle that the foundation level should be above the groundwater level is advisable. In a hydrated ground medium, pressure waves generate high pressures on the walls of the enclosure. Wave reflection effects from the surface of the groundwater table are also amplified. Some plastic reserves of critical cross-sections cannot be used in the design. It is difficult to meet the requirements for effective waterproofing.

Basement walls are very often made of monolithic concrete. As a rule, their load-bearing capacity is not used due to the transfer of loads resulting from the primary function of the building. Their thickness generally results from the conditions for constructing the proper support of the ceiling above the cellars – a rim with appropriate insulation. They are often masonry walls made of concrete blocks, less frequently of solid ceramic bricks. The weakest part of the foundation wall, as a shielding element against penetrating radiation and temperature from a fire, is its plinth part. Hence, two solutions are possible to fulfil the protective function of the part of the wall. The first solution is to assume that the plinth will be backfilled with soil in an emergency. The second is to build a foundation wall of the correct thickness, preferably 0.4 m. The insertion of cellar windows in the enclosure walls of the shelter rooms should be avoided. If necessary for the non-shelter function of these rooms, provision should be made for them to be suitably covered or directly walled up after removing the window sash. The possible covering of these openings and the positioning of the opening frame within the thickness of the wall should make it possible to carry out such work.

The external enclosure of the shelter rooms forms a box – closed by the ceiling from above. From below, it can be closed with a foundation slab structure or, more often, open in the structural sense if only the floor is made on a concrete base and the walls are placed on footings. The foundation slab will be thickened under the walls of the shelter room enclosure. The requirement is to make the box as rigid as possible with all adjacent elements. Depending on its height, the foundation wall is generally at most 2.50 m by calculation, and the spacing of the transverse walls, generally less than 6.0 m, is a surface element stressed in slab-and-disk conditions. The introduction of two-way reinforcement is possible not only for a wall made of concrete but also for a masonry wall in cement mortar. The horizontal reinforcement is then placed in the horizontal joints; in the corresponding vertical cavities left during masonry works, it is easy to make reinforced concrete shafts with vertical reinforcement anchored both in the foundation element – bench or slab. Significant external loads from the earth pressure resulting from the plinth filling and the building's surroundings induced by the crumbling can be carried in the box system of the outer shell of the shelter.

For the insulation of the plinth section, with the rim of the basement ceiling, only veneer-covered insulation of the mineral wool type should be used.

The ceiling covering the rooms intended for the OC shelter should be solid-walled. Reinforced concrete, monolithic and prefabricated ceilings are possible. Prefabricated hollow core slabs may be considered but with load-bearing capacities appropriate for heavy traffic and storage loads. Generally, they will not be typical slabs but custom-made in typical forms. What is not encouraging about their use is the reduced shielding capacity of such a floor both against penetrating radiation and against high temperatures, which is a consequence of the channels in the cross-section of the slab, even when their number is reduced. What is required is to increase the shielding capacity of the ducted ceiling by using layers of appropriate thickness and mass.

The use of hollow core floors should be ruled out. Filigree slabs are currently gaining ground on the market. Using these, it is possible to make floors, essentially monolithic ones reinforced both unidirectionally and even crossed.

A damping layer should be provided on the structural layer of the ceiling to eliminate the effects of impact from rigid masses. At the same time, it can act as a shield for the ceiling structure against excessive heat in the event of a fire. In classic solutions, it was proposed to make it as a sand ballast under the floor-bearing layer. Instead of sand, the ceiling lining was also considered to be made of solid ceramic bricks in cement mortar. Nowadays, hard mineral wool slabs with a top reinforced concrete subfloor may be considered. The recommended flooring solution is terracotta or stone flooring. Eliminate the fire load for fires in levees.

It should be borne in mind that the layer in question can, if necessary, be used as a layer to increase the shielding capacity of the ceiling against residual radiation. In many cases, the requirement will determine the thickness of the layer; it cannot then be lightweight.

The foundation for walls in buildings with a small number of storeys will most often be designed as footings. In addition to their compression in the transverse direction, which is typical of a footing, they should be capable of absorbing reactions from the foundation walls in a horizontal frame arrangement. For such a reason, the footings should be formed with rigid nodes in the horizontal plane. The horizontal insulations must not eliminate the connection of the foundation walls with the footing system and the floor rim.

When designing a slab foundation, it is advisable to form it as a reinforced concrete slab with thickened, battened edges.

5. Summary

The paper indicates the possibility of using some of the material and structural solutions of the housing construction in realising OC shelters built into the basement floor. The construction of free-standing shelters was not analysed separately, but the proposals presented in the paper can be applied to the type of OC shelters as well. Some results of the analysis of the adaptation of material and structural solutions of the housing construction to the needs of OC shelter construction will be presented during the symposium. It is advisable to develop models for the construction of OC shelters using contemporary technologies used in the construction industry.

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