CHAPTER 3
LARGE-PANEL HOUSES

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3.1 Features of architectural and structural solutions of large-panel houses

Large-panel houses are buildings whose load-bearing and enclosing structures (walls, floors, staircases, coverings) are made of large-sized factory-made reinforced concrete panels, one room wide and one floor high, which are assembled on site using industrial methods [3; 84] (see Figure 3.1).

Post-war Europe, especially the 1950s-1970s, was marked by a housing shortage and the need for rapid mass construction [6; 45]. The industrialization of the construction industry led to the standardization of elements and typification of series (for example, in the USSR – series K-7, I 464, P 44, in the GDR – WBS 70, in Poland – “Wielka płyta”, in France – Camus/Tracoba/Coignet) [13; 30; 45]. The key goals that such buildings were supposed to solve were to reduce the labor intensity of work on the site, increase the pace of construction, control quality at the factory, and reduce the cost per square meter. At the same time, standardization gave rise to a stereotyped image and limited individualization of residential areas, which in the 80s and 90s significantly affected, among other things, the social life of the population [32].

Planning solutions for large-panel buildings were based on unified coordination modules (basic pitch 300 mm; large coordination sizes 3M, 6M, 12M). Typical pitch of load-bearing walls 3.0–3.6–4.2–4.8–6.0 m; floor height 2.5–2.8 m (residential), 3.0–3.3 m (public buildings).

The following structural schemes prevail in the volume-planning schemes:

– longitudinal load-bearing walls (corridor or sectional houses with axes of 3.2–3.6 m);

– transverse load-bearing walls (step 3.0–3.6 m, effective for sections with two-sided lighting);

– frame-panel combined solutions (reinforced concrete frame + hinged panels);

– with stiffening cores (staircase-elevator blocks made of monolithic walls with panel floors).

Figure 3.1 – General view of a typical large-panel building

Regarding the sectionalization, it is usually typical for one section to have 2–4 apartments per floor with a vertical core (stairs/elevator). The layout includes compact kitchens of 5–9 m², block-type bathrooms, unified spans for wet areas to minimize water risers (vertical pipelines). Loggias/balconies are often integrated into the facade panels as cantilever elements or attached blocks.

Traditional series have limited transformability: load-bearing – external and part of the internal walls; interior partitions are light. Newer series (P 44T, WBS 70M) have increased spans and variability of plans, the use of hinged panels for internal load-bearing walls.

The external wall panels in large-panel buildings are made of three-layer sandwich panels (external protective layer 50–70 mm, insulation 80–160 mm, internal load-bearing layer 120–160 mm) or two-layer with hinged insulation; insulation materials are mineral wool. Internal load-bearing panels are made of single-layer heavy reinforced concrete with a thickness of 140–200 mm; partitions are made of lightweight concrete/gypsum concrete 60–100 mm. Floors in large-panel buildings are made of hollow slabs (1.2–1.5 m wide, 220–320 mm thick) or solid panels

120–160 mm thick; slabs are supported on two or four sides. Panel joints are made by welding assembly outlets or connecting reinforcement loops with monolithic fine-grained concrete.

Spatial rigidity and strength are provided by a system of load-bearing walls in two directions and by floor disks due to joint work through welding/monolithic joints.

The foundations of buildings are mainly made of strip or more often prefabricated-monolithic strip on pile grillages.

The technology for manufacturing and installing large-panel buildings includes factory preparation of panels in stationary/flow forms. Installation of large-panel buildings is organized as a continuous flow process with a high degree of factory readiness of elements and clear logistics. The panels are delivered to the site in assembled sequence, in marked packages. An important stage is the sealing of interpanel vertical and horizontal seams: laying sealing cords, hydro-dowels, thermal insulation inserts, filling with elastic sealants, arranging ebbs and drip cut-offs for rainwater drainage. Early series often had insufficient thermal conductivity values, cold bridges in the areas of joints, interpanel seams, and balcony consoles. Modern solutions, such as three-layer sandwich panels with continuous insulation, thermal breaks for balconies, an additional external ETICS system, an airtight circuit with vapor barrier from the inside, have improved the situation with thermal performance [15].

Regarding acoustic characteristics, inter-apartment walls 160–200 mm thick made of heavy concrete provide an air insulation index Rw ≈ 52–56 dB. In general, reinforced concrete panels are non-combustible, with fire resistance limits of REI 90–150 for walls and ceilings of typical series; engineering penetrations are sealed with fire-resistant materials; fire-prevention sections are provided in ventilated facades.

Typically, during the operation of large-panel buildings, the following typical damages are encountered:

– interpanel joints: depressurization, freezing, leakage of sealant through cracks; corrosion of embedded parts in the leakage zone;

– cold bridges: balcony slabs, lintel joints, floor ends, joints of three-layer panels with continuity of insulation, facade-window joints;

– carbonization of concrete, corrosion of reinforcement, especially in the joints and drip cutting areas, peeling of the protective layer;

– geometric defects and cracks from shrinkage/temperature deformations.

The energy efficiency of panel buildings is a pressing problem, as most of these buildings were built decades ago according to outdated standards. Panels often have low thermal insulation properties, and the joints between them allow cold and moisture to pass through, which leads to significant heat loss. At the same time, thanks to comprehensive thermal modernization – insulation of facades, replacement of windows and doors, modernization of heating and ventilation systems – it is possible to significantly increase the energy efficiency of these buildings. This not only reduces utility costs, but also increases living comfort, contributes to the durability of the building and reduces the negative impact on the environment [15].

Summarizing the above, it should be said that although large-panel houses are still being designed and built, in general they are positioned as social housing, which allows relatively quickly providing a significant number of people with a place to live and are not as widely used as 50-60 years ago. However, given the significant number of existing large-panel buildings, programs for the modernization and renovation of such houses are incredibly relevant, as proven by European experience [41; 72]. Thanks to thermal modernization in combination with the addition of new architectural solutions to facades, the installation of elevators, and the correction of known deficiencies, mainly related to interpanel seams, buildings gain new life and significantly increase their attractiveness as a place for modern citizens to live.

3.2 Analysis of damage to load-bearing structures of large-panel buildings caused by military operations

This section provides examples of damage to large-panel buildings because of missile strikes, unmanned aerial vehicles, glide and conventional aerial bombs, and rocket and artillery fire in various cities of Ukraine [90].

Figure 3.2 shows the consequences of hitting a multi-story residential building in Zaporizhzhia on March 2, 2023 [82]. A section of a large-panel building was directly hit by an S-300 missile, which destroyed 25 of the 80 apartments and made another 10 uninhabitable. After the missile hit, the upper floors were destroyed due to the blast wave. In general, it should be noted that the V-shaped nature of the destruction is quite typical for missile hits, when after the explosion the first floors remain relatively less damaged, while the upper floors are destroyed. This can be explained by the nature of the action of missile weapons, which strike at an angle of 80-90° to the ground. Also interesting in this case is the fact that when the upper floors were destroyed, despite the action of the blast wave and the occurrence of non-projectile loads, the lower floors under the destroyed ones retained their stability and no cascading destruction occurred, when under the action of increasing loads from above, the lower floor collapses, even if it was not directly destroyed by the action of the shock wave, which indicates significant reserves of the bearing capacity of large-panel buildings to perceive loads applied directly from above.

Figure 3.2 – Consequences of a building hit in the city of Zaporizhzhia [82]

Figures 3.3-3.5 show the consequences of artillery and rocket hits on buildings in the Northern Saltivka area of Kharkiv. It should be noted that at that time the front of hostilities was at a distance that allowed shelling, which is why a significant part of the buildings, in particular large-panel ones – which make up the majority of the housing stock in this area, were damaged [50].

Analyzing the photos shown in Figures 3.3–3.5, it should be noted that single artillery hits do not pose a danger to the building in themselves, and even when one or more external panels are destroyed as a result of direct hits, the adjacent panels generally retain their design position. However, compared to the effects of cruise missiles, a much greater danger to the building is posed by a fire, which can start especially after being hit by shells from multiple launch rocket systems (Grad, Uragan, Smerch, and the like). However, it should be noted that in this case, the metal elements of the assembly joints did not collapse, which prevented the destruction of the entire building.

Figure 3.3 – Multi-storey building on Pivchnaya Saltivka in April 2022 [50]

Figure 3.6 shows an image of the immediate consequences of the rocket attack on Zaporizhia on October 9, 2022 [39]. It should be noted the atypical nature of the destruction, which can probably be explained by the deviation of the enemy missile from the course due to operator error, electronic warfare systems or the results of the air defense systems action. As a result of the above factors, the impact did not occur from above, but perpendicular to the facade of the building on the lower floors, which led to destruction typical of a gas explosion in a building when there is a cascading destruction of apartments located one above the other.

Figure 3.4 – Multi-storey building on Pivchnaya Saltivka in April 2022 [50]

Figure 3.5 – Multi-storey building on Pivchnaya Saltivka in April 2022 [50]

Figure 3.6 – Missile strike on Zaporizhia on October 9, 2022 [39]

Figure 3.7 – Consequences of Russian strikes on Mariupol, March 2022 [21]

Figure 3.8 – Consequences of Russian strikes on Mariupol, March 2022 [21]

Figures 3.7 and 3.8 show some of the hundreds of destroyed prefabricated buildings in Mariupol. The fighting in the city itself lasted for more than 3 months, during which a significant part of it was destroyed. The photos show the consequences of aerial bombardment and direct fire from tanks.

Analyzing the photos shown in Figures 3.2–3.8, it should be noted that a panel building, even when a significant part of it is destroyed because of numerous impacts and fires, does not collapse completely, which indicates a certain autonomy and independence of the load-bearing elements of large-panel buildings.

Figures 5.9 show the consequences of the strike on the city of Poltava, which occurred on February 1, 2024. In general, the nature of the destruction is similar to the consequences of the strike shown in Figure 3.2 on the city of Zaporizhzhia, with the preservation of the "step" with the difference that in this case the impact occurred not in the center of the building but in its upper corner. A fire broke out on the spot. According to the acting chief of the Poltava OVA, the aircraft used a supersonic Kh-22 [89] missile with an estimated warhead weight of 600-700 kg of TNT equivalent. This Soviet missile, designed for attacks on aircraft carriers, has relatively low accuracy and high (compared to Kalibr/Kinzhal) power.

The situational diagram (see Figure 3.10) shows the approximate location of the missile impact, the propagation of the blast wave, and the surfaces of buildings affected by primary and secondary fragments (according to UFC 4-010-01 [97]). Primary fragment is a fragment of a shell or container of an explosive substance or a fragment of an object that has come into contact with the explosive substance, and secondary fragment is a fragment that is formed as a result of the explosion when the blast wave interacts with objects or structures located near the source of the explosion, i.e., parts of structures, machines, small tools, etc.

Figure 3.9 – House No. 7 hit by a rocket in Poltava [89]

After inspecting the surrounding buildings, it was discovered how the blast wave spread. Thus, after the impact, almost the entire entrance was destroyed, except for one apartment on the first floor. It is visible that the neighboring house No. 5 also received damage due to the impact of fragments from the explosion and the blast wave. It should be noted that it reflected the wave and it spread back. This is indicated by the partially damaged windows of house No. 7 on the opposite side from the impact. On the other hand, the blast wave passed along the tangent of house 7A, reaching preschool institution No. 2 and the houses opposite. Due to the non-linear configuration of the kindergarten building, the impact of the blast wave also spread to the surfaces inside between the ledges, causing damage to the windows. Small fragments of panels were found not far from the house No. 1A, which also indicates that the blast wave reached it, but its energy was not enough to cause damage.

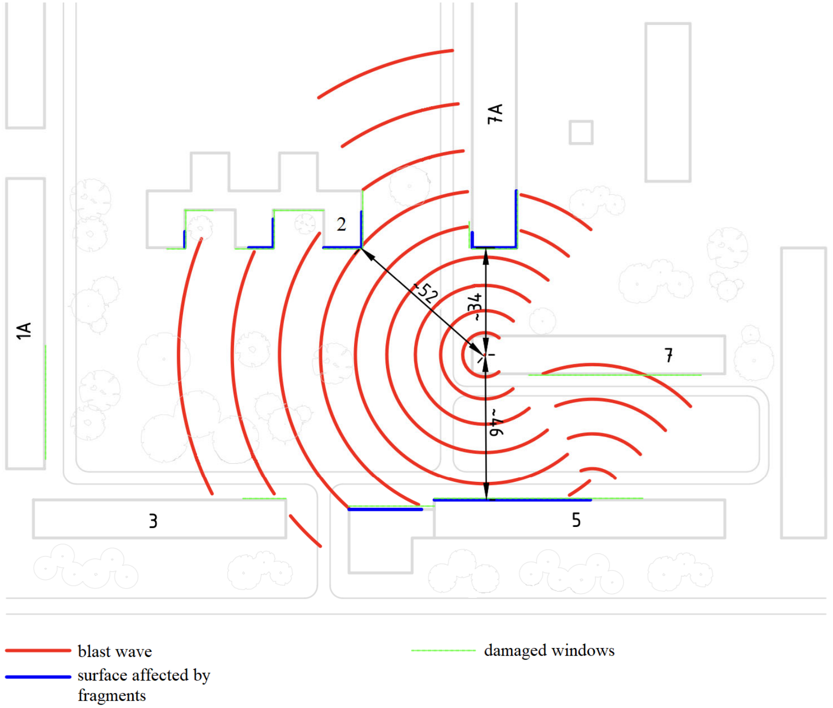

Figure 3.10 – Situational diagram of the location of houses [88]

The house No.7A (see Figure 3.11) [89] suffered the most from the debris, as it was the closest and the impact probably came from its side. Upon examination, the greatest damage from the debris was in the weakest parts of the panel – the window openings. Along the house, where the debris flew tangentially, there is minor damage to the protruding balcony structures. On the opposite side, parallel to the house hit by the rocket, is house No. 5, which was also damaged by debris, as can be seen in the photo (see Figure 3.12): the facade of the house is chipped, and in some places the debris is stuck in the concrete panel. Preschool institution No. 2 was also hit, where the inspection revealed depressions in the brickwork. In the kindergarten itself, debris was also found, which broke through the windows and passed through the room closest to the explosion site (see Figure 3.13) [88].

The partially surviving panels of the apartments on the first and second floors of the right wing of the entrance will also have to be dismantled, since further operation of such premises is dangerous, since the joints of the concrete panels were damaged, and the panels themselves changed their position relative to each other (opening of seams, deviation of the panel from the vertical position, formation of cracks as shown in Figure 3.14).

Figure 3.11 – Damaged façade of a house No.7A [89]

Figure 3.12 – Damaged by debris and blast wave, the facade of a house No.5 [89]

Figure 3.13 – Damage to preschool educational institution No. 81[88]

Figure 3.14 – Opening of seams and damage to the joints of the panelsof the entrance group of the first entrance

3.3 Generalization of damage to large-panel buildings caused by military actions

When summarizing the damage to large-panel buildings caused by military operations, it is worth starting from a combination of two groups of factors: the nature of the impacts (impact, explosive, thermal, fire, debris, progressive destruction) and the specifics of the wall prefabricated system itself with its typology of nodes, joints, and repeating elements. An explosive load on the facade or inside the building generates short-term high-pressure pulses that act perpendicular to the plane of the panels and floor disks, and also cause significant loads during wave front passage and reflection. For large-panel buildings, the most vulnerable are the external three-layer panels with zonal weakened areas around openings and joints, as well as the nodes of the floor slabs resting on the internal and external load-bearing walls [56; 98]. In the case of an external explosion, local failure of the outer protective layer of the sandwich panel (chipping, separation from the inner plate connected by anchors) and destruction of the finishing layers and insulation dominate, while the load-bearing inner layer undergoes cracking from bending and membrane forces; in the case of a closer detonation, complete breakdown and loss of the load-bearing capacity of the facade section are possible. In addition, damage is caused by fragmentation of secondary elements: glazing, loggia fencing, and mounted air conditioner units, which create dangerous debris and an additional local threat to the building and people [71; 91].

Internal explosions (within an apartment, entrance, or technical rooms) are more dangerous in terms of progressive destruction, as the shock wave interacts with the floor disk and transverse walls, causing slabs to separate from the supporting shelves, failures of embedded parts, and shear displacements at the joints. A typical scheme with 60–90 mm support of hollow core slabs and a “loop-loop” connection or short embedded bars is susceptible to brittle separation of welds if the welds have previously been weakened by corrosion or do not meet design quality. There are known cases when the local loss of one or two supporting sections of the slab caused the disk to “overturn” and the cascading collapse of the floors due to the lack of membrane action and insufficient anchoring to adjacent walls. In wall systems where spatial rigidity is provided by a combination of cross walls and floor disks, gaps in the joints reduce the joint work, transferring some of the elements to the cantilever mode with an excess of design moments and shears. If the explosion is combined with fire, the increase in temperature in the seams and on the steel embedded parts reduces their strength and rigidity, accelerates the progress of corrosion, and in the area of loggias and balconies, thin cantilever sections are destroyed, which are often bridges of cold and have a deficiency of a protective layer.

A separate category is damage from shrapnel, bullets, and debris. They rarely lead to an instant loss of load-bearing capacity, but cause multiple local spalling of concrete, penetration of thin outer layers of sandwich panels, ruptures of vapor and waterproofing membranes, and penetration of insulation. Such “dissections” of the facade envelope are transformed into long-term operational risks: wetting, freezing, accelerated carbonization of concrete, corrosion of reinforcement and embedments, deformations from freeze-thaw cycles. Even small cracks in the joints become paths for capillary wetting, and if the sealants have been outdated or lost from impact, water penetrates the reinforcement joints and causes further corrosion. During systematic shelling of facades, repeated microdamages accumulate, grow into a network of cracks, and the delamination of the finish and thermal insulation increases the wind load on the remaining panels, which can lead to secondary detachments during storm winds.

Of great importance are the initial defects inherent in some old series of large-panel houses: insufficient sealing of interpanel seams, cold bridges at the joints of slabs and facade panels, undersized thickness of the protective concrete layer, and uneven quality of welded joints. Under the influence of an explosion, these “weak spots” become initiators of destruction. In buildings with a high number of floors (9–16 floors), the role of stair-elevator units is enhanced; their walls are often monolithic or prefabricated-monolithic, and they must withstand significant shear loads. If their joints are damaged, the building loses its main “backbone” of rigidity, which is manifested in increased horizontal movements, the appearance of diagonal cracks in the piers and stress concentrator zones – near openings and corners [62; 73].

Fires that accompany destruction from explosions or shelling have a combined effect: they destroy external insulation systems, worsen the thermal insulation properties of sandwich panels, and affect the deformation state of assemblies. Mineral wool insulation retains its non-flammability, but loses its mechanical integrity, settles, opening cavities; organic insulation can degrade or catch fire. PVC frame windows and double-glazed windows that cannot withstand prolonged heat exposure fall out, and then wind pressure and soot/moisture deposition additionally load the internal partitions and slabs. High temperature accelerates carbonization and degradation of the concrete protective layer [27], especially where its thickness was minimally acceptable; with further moistening and cooling, a network of cracks and chips forms. In balcony consoles and loggia ribs, which are often thin, chipping of edges is observed, loss of load-bearing capacity of supporting elements of fences and anchors is observed - this creates a danger of fragments falling outside.

Damage to foundations and underground parts in large-panel buildings is usually associated with nearby high-power explosions or repeated shock loads, leading to uneven settlements and displacements of the grillages. In such cases, vertical walls perceive additional out-of-plane moments, which results in vertical and angular cracks, "steps" at the seams, wedge-shaped openings in the basement/first floor piers. Damage to basements and technical undergrounds, especially if engineering highways are located there, causes secondary consequences: flooding, aggressive environment, rapid progression of corrosion of embedded parts and reinforcement, freezing in winter. For panel walls, "separation" from the foundation beams or weakening of the anchorage of the embedded elements at the lower edge is dangerous, which can manifest itself both in local subsidence and in skewing of sections with loss of joint tightness.

It is necessary to distinguish a category of non-catastrophic, but massive damage, which determines the scope of restoration work and operational risks: these are depressurization of vertical and horizontal seams, cracks in the places where internal walls adjoin external ones, weakening of putties and plasters in joints, corrosion of exposed embedded and mounting loops, local collapse of layers of facade thermal insulation or tiles. Even without complete loss of load-bearing capacity, they form "open" loops for moisture, which in the medium term becomes a structural problem. In areas where buildings were exposed to prolonged background vibration from shelling, loosening and opening of joints, disruption of layers under "floating" screeds, degradation of soundproofing inserts are recorded, which worsens acoustic comfort and increases the risk of impact noise transmission between apartments.

From the point of view of user safety, elements that lose stability or can separate from the main structure are critical: parapets, canopies, hinged panels, loggia filling, ventilated facade cassettes, unsecured or partially secured balcony railings. So, after an explosion, even insignificant wind loads can provoke fragments falling from a height. Equally dangerous is the internal "pulling out" of floor slabs from supports due to creeping deformation in destroyed joints, in particular in areas above driveways, shops on the first floors or technical openings, where the support lengths are already reduced.

Approaches to temporary safety include unloading dangerous spans with struts, installing external steel frames or belts to intercept the disk action of the floors. At the apartment level, dismantling emergency balcony fences, securing visors and parapets, and local sealing of cracks and seams to counteract moisture. For nodes with a probability of progressive destruction, more stringent measures are used: temporary frame portals under the slabs, grouting of joints and the arrangement of additional monolithic belts connecting the wall panels into annular diaphragms. In areas with impaired rigidity of the stairwell and elevator cores, a quick monolithic clip-on "cover" or the installation of steel X-ties in the light openings is effective.

If the supports of the floor slabs are damaged, local reinforcement is performed with steel angles/channels, which form an additional support shelf, as well as anchoring the slabs through through-beams with overlays; in the case of significant loss of anchors, partial monolithic installation of belts or new ribbed sections of the floors is advisable. For internal load-bearing walls, it is possible to concrete with clips, install additional diaphragms in places of lost elements. If diagnostics fix systemic degradation of the joints in height, it may be economically justified to install an internal or external steel frame that will take the main loads – this speeds up the return of the house to operation with minimal intervention in the apartments.

Engineering networks and their damage form a separate front of work. Explosions often destroy ventilation ducts in panels, which leads to smoke flowing between apartments, as well as loss of draft. Water and heating risers, when slabs and walls shift, break at the nodes of passages through structures, flooding sections and accelerating the destruction of seams. Restoration requires not only replacing pipes and fittings, but also retrofitting penetrations with fire-resistant sleeves, restoring tightness and sound insulation, balancing heating systems, and installing ITP for load management.

Organizationally, it is important to divide buildings into accessibility zones: emergency, limitedly usable, and usable with restrictions. This classification determines programs for temporary shelter, “quick” rain protection (film systems, temporary facade screens, closing windows with plywood), as well as the priority of major repairs. On an urban planning scale, large-panel arrays have common engineering networks, entrances for heavy equipment, and cranes, which affects the logistics of restoration: it is often advisable to carry out work “section by section” with mobile sets of traverses and scaffolding, organizing facade and interior work in parallel in order to reduce the time for returning housing [24].

At the durability level after restoration, preventive measures are required to reduce future risks. This includes systematic restoration and modernization of joints using elastomers and hydro-dowels, the use of corrosion-resistant embeddings and anchors, increasing the thickness of the protective layer in the repair areas, local cathodic anti-corrosion protection of reinforcement in critical nodes, and the installation of a continuous thermal circuit to eliminate wetting and freezing. On facades, it is advisable to implement systems that allow the replacement of damaged cassettes/panels without dismantling large areas, as well as design “controlled” unloading paths in the event of emergency events, for example, additional connections between floors and cores that can keep the slabs from falling out.

Thus, the spectrum of war damage to large-panel buildings ranges from local loss of the shell to critical failures of load-bearing elements. Vulnerability is exacerbated by age-related degradation of joints and materials, sealing defects, and corrosive wear. The key to safe and effective restoration is rapid and accurate diagnosis, prioritization of measures that prevent progressive destruction, and comprehensive reinforcement of the building’s spatial performance. Combined with envelope and engineering upgrades, this not only allows buildings to be returned to service, but also increases their resilience to future extreme impacts, minimizing the social and economic consequences for residents and the city.