Design and Construction of a Low-Rise Residential Building on a Landslide Slope

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Abstract. The implementation of national projects such as “Housing and Urban Environment” creates difficulties in the implementation of the national project “Ecology”, since the massive demolition of dilapidated and damaged housing leads to solid household waste. In the context of the ever-increasing intensity of urban development and the growing land shortage, the problem of designing and constructing low-rise residential buildings on unsuitable territories in engineering and construction, especially on steep slopes, is of particular relevance. The article is devoted to the experience of designing and constructing a residential building on a landslide slope according to an innovative technology that involves the reuse of reinforced concrete structures and building materials obtained during the demolition of buildings. A special feature of the construction is the use of small-sized construction equipment when excavating and installing prefabricated structures, including reusable building materials, products and structures, which made it possible to drastically reduce both the labor intensity and the cost of construction and installation works. The article provides examples of non-typical use of reinforced concrete slabs, floors, as the design of prefabricated monolithic foundations. The novelty of the applied solutions is confirmed by the patents of the Russian Federation.

1. Introduction

The program of resettlement of citizens from emergency housing in the city of Voronezh began to be among the first in Russia within the framework of the federal project “Ensuring a Sustainable Reduction of Unsuitable Living Housing”, which is part of the national project “Housing and Urban Environment”. It is designed for the years 2019-2025. In the city of Voronezh, 540.5 thousand square meters is liquidated. As a result of the massive demolition of buildings and structures due to the appearance of huge volumes of construction debris (1 m. project "Ecology". At the same time, the experience of reuse of materials and structures is well known, in the construction of low-rise buildings and structures, in the construction of access roads, within the village roads, which makes it possible to drastically reduce the cost of constructed housing. At the same time, mechanisms of direct participation of citizens in the formation of a comfortable urban environment are created [1, 2].
An important problem of the right coast of the city of Voronezh is the construction in difficult hydrogeological conditions with difficult relief.

There are many examples of successful use of the conditions of the relief during construction at different periods in history. Success in this regard is reached out to the city planners of ancient Greece, the Middle Ages, the Renaissance. Careful consideration of the conditions of relief is typical for Russian urban planning [1].

In the modern world, city planners work together on representatives of the related sciences and industries (geomorphologists, hygienists, transport workers, climatologists, etc.) on specific aspects of urban planning in complex relief. The features of complex relief make every time look for a new solution that is most appropriate for a particular situation [3-10].

One of the main tasks of urban planning is to summarize the experience of taking into account the structure features of the relief in the design of buildings that provide low construction costs.

2. Relevance

In world practice, designers are guided by national aesthetic values. Schemes of various types of residential buildings for construction on difficult terrain are being developed. The typology of housing according to the layout method organizes the diversity of housing in a given area and provides an opportunity for designers to choose the most suitable type of house in difficult terrain conditions [6].

Special attention is paid to the consideration of the universal property of the relief. As known, it is a visually perceptible part of any architectural object. Architecturally - aesthetically, the complex relief reveals great opportunities for creating an expressive, unique look of the city [5].

The house built at the address house 5а, Krasnenkaya Street, the city of Voronezh, Russia, is well received from the Chernavsky Bridge and harmoniously fits into the environment. At the same time, from the terrace of the house, the night view of the left-coast part of Voronezh bewitches with its views.

It should be noted that the development of complex terrain leads to an increase in construction costs due to the large amount of manual labor in setting up monolithic reinforced concrete structures, little experience in using construction equipment, the impossibility of using prefabricated reinforced concrete structures because of their massiveness. The negative aspects of the placement of buildings on the slopes are associated with the solution of specific problems of its organization and implementation. Greater complexity is the solution to the following tasks: ensuring the work of earthmoving and lifting equipment; the choice of ways to protect the construction site from the flow of storm water; device access roads.
Another aspect of the effect of complex relief on the placement of buildings on the slopes should be mentioned. This is the danger of slope instability (landslides and landfalls). These issues should also be taken into account when developing construction technology on landslide slopes.

From the above it follows that the design and construction of buildings in complex terrain conditions require a scientific approach. The scientific and methodological foundations of such design and construction should be expanded through the introduction of new innovative developments [21-23].

This defines the purpose and objectives of the study.

3. Purpose of the study

To develop a project for a low-rise residential building and effect its implementation with the re-use of thin-walled reinforced concrete slab structures as the foundation and walls of the basement, formed during demolition of dilapidated and emergency housing, taking into account various aspects of the impact of complex relief.

Objectives of the study:
- to summarize the experience of designing and constructing a residential building on a landslide slope;
- to develop an innovative technology for constructing continuous slab foundations of box-section from ribbed floor slabs, providing a significant reduction in the cost of laying foundations on landslide slopes;
- using the example of the implementation of a low-rise residential building object on a cleaved surface in difficult terrain conditions, to prove that the developed technology is progressive and effective
- prove the rationality and safety from the point of view of the ecology of the use of reinforced concrete structures obtained after the demolition of buildings;
- Summarize the experience of using small-sized earth-moving equipment in the production of earthworks on a landslide slope, which dramatically increases the speed of construction.

4. Theoretical part

The object of the research is the experience of design and construction of a low-rise residential building on Krasnenkaya Street, 5a in the city of Voronezh (Russia). House drawings are shown in Figures 4-9.

The house was built on a landslide slope in 2015. The building has simplified geometric forms expressing the inner content (functional processes are expediently organized) with the help of rational structures made of reinforced concrete, brick, gas silicate, etc.

Such an approach to design is characteristic of the direction of functionalism. The term “functionalism” covers diverse and contradictory trends in the “new architecture” of various countries after the First World War. The leaders of functionalism are Walter Gropius and Ludwig Mies van der Rohe, Gropius and his followers in their works emphasize that the appearance of structures should be determined by the economical use of space, material and money [14-23]. This opinion was fundamental in the development of the project of the house under consideration.

Further, it should be noted that a sharp change in the natural structure of the relief is associated with high monetary costs and a violation of the general picturesque of the site. Therefore, it is rational to create terraces for individual buildings or their parts in areas with a significant bias. Their sizes can be various. The main means of interfacing the terraces can be: green stripes, slopes, retaining walls [3]. When placed on the site of buildings with terraces, the task of adapting them to the relief arises, which can be solved by creating a basement floor, the northern side of which has no windows and is underground, and the southeast direction has a large glass area.

Our house is an example of the adaptation of low-rise residential building to the relief. It is located on two terraces. On the first terrace with a mark of -3.600 m there is a ground floor (fig. 4), where there are day premises (a common room and a kitchen) with a separate entrance from the courtyard.
The courtyard is functionally combined with the hall and kitchen located on the ground floor. A special feature of this terrace is that the slope and the house facing the terrace protects the terrace from the north and north-west winds, which allows you to create a cozy place to relax even in windy weather. Trees and shrubs planted around the edges of the terrace, perform the function of strengthening and aesthetic pleasure. Bedrooms with pantries and bathrooms are isolated. They are located on the first and second floors (fig. 1-3). The second entrance to the house is from the street (from the second terrace) through the vestibule (fig. 5). At the same level is the entrance to the garage. All rooms are connected in height by a double-march ladder located in the middle zone of the house.

![Figure 4. View from the reservoir.](image1)

![Figure 5. View from the courtyard.](image2)

The volume of the house in question has a stepped shape. Such special types of houses for construction on the slopes were used in the 70s, 80s, and studies of a number of specialists proved that the economic functional indicators of these houses are no worse than those of houses being built on gently sloping territories [3, 4]. Their shape is close to the configuration of the relief, they can be built on the edges of the slopes. In this example, the partial introduction of a residential building into the ground, as well as the division of large volumes into parts, contributes to its coordination with the scale of the landscape (fig. 4-5). When perceived by the reservoir, the building looks like an accent element in the natural landscape.

5. Implementation of the construction part of the project

The construction of the house was complicated by several factors: the presence of a slope with a slope of more than 45%; constrained conditions during the work of construction equipment; the presence of a dense to the object of power lines; the presence at the base of the foundations of a large amount of alluvial and bulk soil

Because of the limited budget, it was decided to apply used reinforced ribbed slabs in the construction of foundations and walls to reduce the cost of the building. As materials for the walls, trimming gas silicate blocks are used. It was decided to reconstruct the old garage and use it as part of the house, for which an inspection of its supporting structures was carried out, the survey showed the need to strengthen the soil under the foundations for the garage. When reinforcing the foundations, short driven piles were used, and the foundation of the garage itself was “transplanted” to a slab monolithic reinforced concrete foundation.

Stages of construction:
1. Due to the large amount of excavation work and the impossibility of using conventional excavators, Hitachi EX 40U was used, which the crane could bring to the slope. The high performance of the excavator dramatically reduced the laboriousness of earthworks, the timing of their implementation. The excavator was used both for cutting alluvial soil and dumping it on a slope, preparing the soil for the ground basement and at the same time creating a terrace in front of the house, increasing the usable area in front of the house.
2. The presence of nozzles on the excavator made it possible to seal the sandy base;
3. On the prepared base waterproofing from polyethylene film was placed. Sanding was performed
on top;
4. After that, the installation of thin-walled foundations made of ribbed slabs obtained after dismantling buildings was carried out;
5. When erecting the foundation after laying ribbed reinforced concrete floor slabs, a layer of roll-up waterproofing was laid on top of them, a heater was laid on top of it, and then filling with slag was laid with soil;
6. Next was the installation of the walls of the basement of ribbed plates;
7. Overlap of the basement floor slabs;
8. Top of the slabs was made of gas silicate blocks and bricks;
9. Bearing walls were blocked by slabs of the first floor;
10. Next, masonry of the walls of the second floor was made of scraps of gas silicate with obligatory reinforcement with welded meshes, which allows to increase the bearing capacity of the walls [22];
11. The device combined roof;

In the construction of this house and a number of low-rise residential buildings in the city of Voronezh, inventions were used that belong to VSTU [23-25].

Construction of houses from reusable materials was carried out by professional performers-builders, under the guidance and supervision of employees of the Department of Building Constructions, Bases and Foundations named after Professor Borisov Y.M., which ensured the correctness and scientific validity of the selected engineering solutions. The quality control of materials and structures, including reuse in terms of ensuring the strength characteristics of building materials, products and structures, was carried out at the Center for Collective Use of the VSTU, which ensured the reliability and safe use of reuse materials.

During the construction of the wall foundation of the house number 5a along Krasnenkaya Street of the city of Voronezh (Russia), a slab foundation was first erected, then ribbed floor slabs were installed on it vertically, with ribs inward. Next, welding of the lower longitudinal edge of the vertical wall plates to the base plates was carried out. The space between the stiffeners of the wall plates was filled with clay and slag, after which the facing was made with bricks. The mixture of clay and slag in this design acted as a heat-insulating material, and also regulates the heat-humidity regime.

The advantages of this design are:
- large bearing area, which reduces the load on the ground;
- the lack of significant excavation, as the foundation does not require a deep pit;
- simplicity and high speed of installation in comparison with the monolithic foundations;
- technical result is to improve the technological development of construction work, reducing the weight of the structure and its cost due to the re-consumption of reinforced concrete slabs obtained during the demolition of buildings and structures.

The disadvantages include:
- the need to attract lifting mechanisms for laying plates, as well as the device access roads for transport, delivering them;
- lower stiffness compared to the monolithic slab, filled with reinforcement at the construction site;
- great difficulty in arranging the basement.

A prerequisite for justifying the reuse of building materials and structures was the assessment of residual lifetimes, which was carried out using methods and techniques developed under the guidance of Professor G.D. Shmelev, [7-8, 11-13, 26]. The use of these methods and techniques made it possible, even at the disassembly stage, to determine the suitability of various materials and structures for their reliable and trouble-free further use during a long period of operation of a newly constructed residential building.

6. Practical significance
Repeated use of structures and materials and the described construction technology has significantly reduced the cost of 1 square meter house. It amounted (without internal and external finishing) to
75.28 Euros (approximately 5.5 thousand rubles), which is significantly lower than the established prices in the city of Voronezh (from 30 to 50 thousand rubles per 1 sq. m. of housing without finishing) for mass high-rise and cottage construction. The considered technology allows for ecological construction in difficult geological conditions (fig. 4-5).

The reliability of the use of structures and materials provided guidance and supervision over the construction of the staff of the Department of Building Constructions, Bases and Foundations named after Professor Borisov Yu.M. The quality and compliance of the strength indicators of construction products and structures with the requirements of the project and regulatory documents was monitored by certified specialists of the Center for Collective Use of VSTU.

7. Findings

The problem of disposal of construction waste without exporting it to the landfill of technical and household waste, as well as the development of unsuitable territory for the construction of the site on a landslide slope was solved. The developed technology expands the scientific and methodological foundations for the construction of residential buildings on difficult terrain, and allows to solve the specific tasks of its organization and implementation. In architectural and aesthetic terms, the complex relief reveals wide possibilities for creating expressive architectural solutions.

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