

Some features of the structural systems of houses built from materials

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Abstract. This paper discusses the technological and design features of houses built from local clay materials, in particular, those built from a wooden frame filled with clay materials called "synch" and from adobe or clay materials of irregular shape "pakhsa". Such buildings built from local materials, as a rule, related to buildings with walls made of low-strength materials, were mostly erected without observing technological, anti-seismic measures and are characterized as the most vulnerable in seismic terms. A comparative analysis of the technology of erection by the owners themselves with some violations and the technology of erection proposed by us in compliance with the rules during the construction process was carried out. In houses built using the "synch" technology, foam balls (expanded polystyrene) were used as a filler to reduce the mass of clay, the optimal ratio of clay and expanded polystyrene was revealed, in the course of research we received a patent for a modified clay material with expanded polystyrene. And also, the results of testing models of houses built from a wooden frame filled with clay materials (synch) and from clay materials using the "pakhsa" technologies are given.

1 Introduction

Construction with clay materials originated in ancient times and is widely used in Asia Minor, the Middle East, Southeast Asia, China, North Africa, Southwest Europe, the southwestern United States, South America, as well as in many other areas of the globe, where this type of construction is economically viable.

The ability of clayey soils to be easily moulding and the presence of a certain mechanical strength have long attracted attention, and therefore such soils began to be used as a raw material. An example is some of the many earthen structures built in the 17th-19th centuries that lasted over 150 years. In the Leningrad region, the Priory Palace, built at the end of the 18th century, has been preserved. In 1609, in Santa Fe (New Mexico), a governor's house was built from raw stones. Over 10,000 earthen buildings have been built in Australia. There are also ancient earthen buildings in England, Scandinavia, Italy and Spain. In France, near Lyon at the end of the XVIII century built from rammed clay soil 6-storey building of the lace factory. In Germany, many one-, two-, and three-story buildings

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made of clay-organic materials were built. For more than 260 years a two-storey building with mud walls stood in Risdorf, and in 1903 another storey with walls made of fired brick was built on top of it [1, 2].

In the city of Kirov, there is a well-preserved adobe house built in the 80s of the last century. In Russia, fire-resistant adobe construction arose at the end of the 16th century, when the "Stone order for managing the construction business" was founded in Moscow. Adobe buildings in the USSR and in Central Asia, in Ukraine, the North Caucasus, and in the Crimea were widespread in the 19th century. At the beginning of the 18th century, after one of the great fires in Moscow, the construction of wooden residential buildings was prohibited and it was proposed to build adobe dwellings. At the end of XVIII century, in the village of Nikolskoye, Novotorsky district, N.A.Lvov established the "School of earthen beaten construction to provide villagers with durable and cheap housing and the preservation of forests in the country," and in the early XIX century was published first "guidance on the construction of adobe buildings and adobe roofs. During the XIX and early XX centuries raw and adobe production has become widespread in a number of regions of Russia. So, for example, in 1872 in the former Samara province there were 181 completely suitable buildings made of mud brick, and in 1887 there were already 21681 buildings; in Tashkent (in the Russian part of the city) in 1909 there were 702 residential buildings, of which 323 had mud walls [2].

It should be noted, however, that during the construction of mud-brick buildings in many cases elementary building rules are not observed, which leads to various defects, which builders undeservedly attributed allegedly to the negative qualities of clay-organic materials. Clay was labeled "building material for the poor". However, as is often the case, the wheel of time took a complete turn, and clay as building material again appeared on construction sites - of course, at a new quality level. In Germany, there is a renewed interest in building with clay. Klaus Schilberg, author of many books on building with clay and other natural materials, is convinced that the building material of our ancestors has a place in the future.

In difficult times around the world, clay was often the primary building material. In one of the books on construction of the early 17th century you can read that at that time, due to the shortage of apartments, with the rising cost of wood and other building materials, the number of clay houses increased dramatically. After the world war, in 1919, due to the lack of coal, the production of cement and bricks fell sharply, and people were again helped by clay. Another upsurge in the construction of earthen houses came at the end of World War II, caused by the energy crisis.

However, the reason for the resurgence of interest in building with clay in modern Germany these days is not poverty. Clay is non-toxic, is one of the most environmentally friendly building materials and is almost one hundred percent recyclable. Construction waste when using clay is not formed, it can be returned to the environment without harm to nature, which is very important in an era of environmental degradation, depletion of natural resources and chemical pollution. Due to its considerable thermal mass it can be used in passive solar heating systems. The general interest in environmentally friendly building materials has allowed us to evaluate the properties of this material in a new way. Firstly, it does not need to be brought from far away, it is literally under our feet. Secondly, for the preparation and processing of clay does not require significant energy costs [3, 4].

The relatively low seismic resistance of earthen structures is the main disadvantage due to the very low bearing capacity of earthen walls, strength characteristics in bending and compression. The main causes of destruction during earthquakes and other natural disasters are non-compliance with anti-seismic measures during the construction of low-rise private houses, poor quality of building materials and non-compliance with construction technologies. In [2, 5 - 8], several solutions for strengthening residential buildings made of

clay materials and assessing the threats of technical risk during construction are studied in more detail [9].

Based on the analysis of statistical data on buildings of individual residential development in the Kyrgyz Republic, practically used individual residential buildings were classified by us according to the types of load-bearing structural systems. According to this classification, about 40% of the buildings are built of mud bricks or regular blocks; about 15% of buildings have a wooden frame filled with clay materials or houses built using the synch technology; about 25% of the buildings were built of adobe using the sokmo and pakhsa technologies; about 20% of the buildings have a reinforced concrete frame filled with clay materials [6]. Clay and wood combine and complement each other perfectly. Staying in clay preserves the wood, i.e. protects it without the use of pesticides. Old buildings clearly demonstrate how well preserved the wooden structures are in the clay walls. Therefore, of the four listed types of structural systems of houses built from local clay materials, we will dwell in more detail on two types that are suitable for residents living in hard-to-reach, mountainous conditions. The main load-bearing elements of such structures are clay and wood, these are "synch" houses, which are a wooden frame filled with clay materials, and "pakhsa" – houses with monolithic walls made of clay materials.

2 Technological and structural processes of building houses from local clay materials

The wooden frame of the "synch" house consists of lower and upper beams, beams, struts, spacers and has a filling of clay materials (Fig. 1).



Fig. 1. Synch house model.

The construction of the house model began with the installation of the formwork for pouring the foundation on the seismic platform. In the formwork, we placed the embedded parts made of smooth reinforcement $\text{Ø}6\div 8$ mm and wire $\text{Ø}3$ mm for strapping. For pouring

the foundation, a concrete mixture of cement, sand and crushed stone was prepared in a ratio of 1:2:3.

To lay beams with a section of 100×100 mm on the foundation, holes were drilled in the beams in those places where there are wire outlets for strapping. The beams were laid in pairs in such a way that a gap of 50 mm wide formed between them. Then the beams were tied with wire. A hydroisol was used as a waterproofing between the foundation and the beam.

To form the frame of the walls, racks in the form of boards with a section of 100×50 mm were installed in pairs on beams in the corners, as well as in places where door and window openings should be located. To give stability to the frame between the uprights, cross-shaped spacers with a cross section of 50×40 mm were fixed, and horizontal spacers in the form of jumpers were given to form door and window openings. The structure of the frame is completed by the upper beams, which were fixed at the top of the props. On them are laid wooden floor beams with a spacing of 500-700mm. For coverage fiberboard was used, which was laid on the floor joists and fastened with self-tapping screws. For the roof, rafters and purlins were constructed and metal tile was used. A front door and glazed window frames were then installed in the openings.

To reduce the weight of clay, granulated polystyrene foam $\text{Ø}5$ mm and density of $15 \div 20$ kg/m³ were used as an aggregate. To identify the optimal ratio of clay and polystyrene foam, samples-cubes $100 \times 100 \times 100$ mm in size were made and tested in compression (Fig.2). During the research we received a patent for modified clay material with polystyrene foam [10].



Fig. 2. Modified clay material with polyfoam.

The bucket was filled with clay, poured with water in the required amount and kneaded with subsequent incubation until the desired consistency of the clay solution. Then polystyrene foam in an amount of 0.5% of the clay mass was added to the prepared clay mortar and thoroughly mixed. The resulting semi-dry mass was filled into the frame, having previously constructed a formwork of plywood. To speed up the process of preparing the clay mortar and the turnover of the bucket, the prepared clay mortar was unloaded on the concrete floor, and the bucket was filled with clay and the process was repeated all over again.

The next step is to apply plaster to the surface of the walls. After the walls dried, twisted polymer thread (twine) $\text{Ø}3$ mm was used to reinforce them. On the inner and outer surfaces

of the walls, nails 100 mm long were pre-drilled at 10 cm intervals, followed by tying in the form of a grid with this thread. In order to ensure the elastic performance of the mesh, a $10 \div 15$ mm gap was left between it and the wall. For plastering, a complex cement-sand-lime mortar was used in a 1:4:1 ratio.

When building a residential building from local materials such as "Synch", we recommend the following technology or rules for conducting basic construction work:

- when pouring the foundation, two rows of double tying wire 100 mm long are laid in its body, at a distance of 100 mm from the outer and inner edge of the foundation, with a spacing of 300-400 mm. After the concrete foundation has gained strength, it is preliminary covered with roofing felt (technoizol), having made technological holes on it for the outlets of the tying wire. Next, it is laid in two rows of longitudinal beams $\text{Ø}100$ mm so that between them there is a gap width of 150 mm, and tie them with tying wire, released from the foundation. Cross bars with a section of 50×50 mm and a length of 400 mm are attached to the beams with nails or binding wire, with a spacing of $200 \div 300$ mm, thus forming a grid. Thus, the connection between the foundation and the future clay material wall is ensured (Fig. 3, 4);

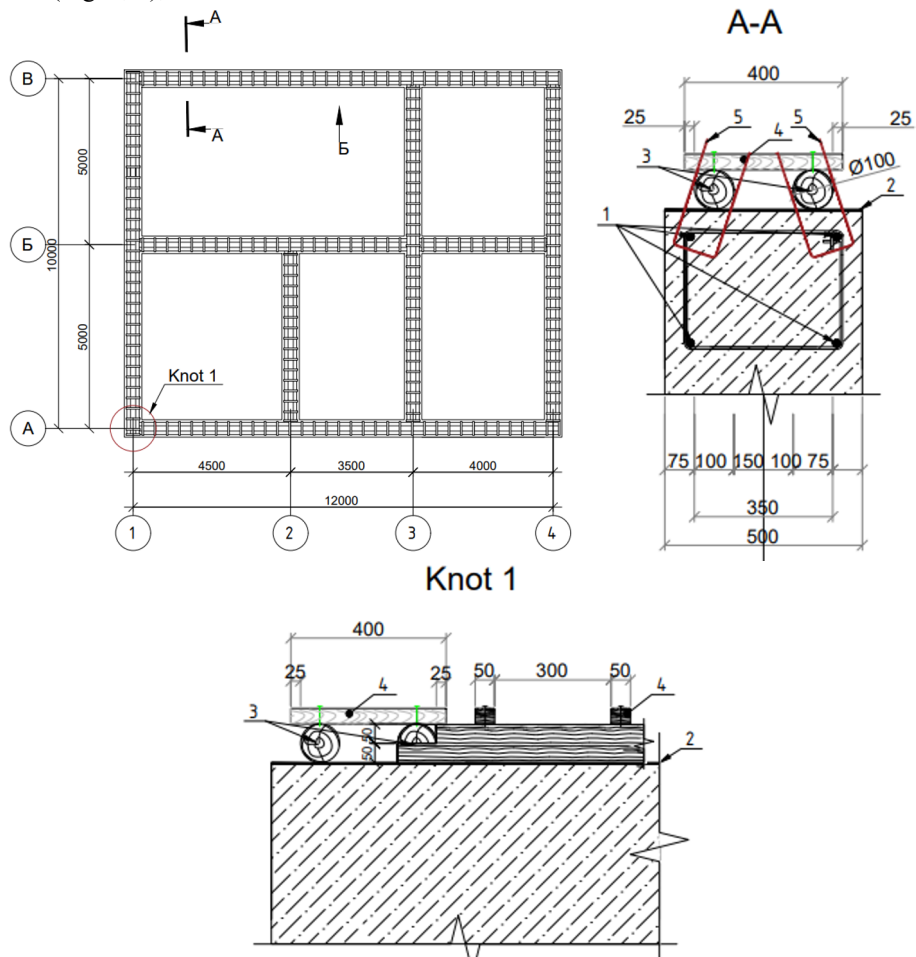


Fig. 3. Plan at the foundation level: 1 - longitudinal reinforcement $\text{Ø}12-14\text{mm}$; 2 – waterproofing; 3 - longitudinal wooden beams section $100 \times 100\text{mm}$ or $\text{Ø}100\text{mm}$; 4 - cross-section wooden laths $50 \times 50\text{mm}$ or $\text{Ø}50\text{mm}$; 5 - tying wire.

- removable formwork is installed. From the prepared clay dough with the help of a shovel and a hoe, you need to separate a piece of clay mass, throw it on the straw scattered in advance, wrap it well (gualak), and lay it by hand around the entire perimeter of the formwork. The first row of the wall is laid with a height of 600 mm. On top of the first row of the wall, a wooden mesh is laid, made of longitudinal and transverse rods with a cross section of $\text{Ø}20$ mm. It is very important to note that the length of these transverse rods should be 50-60 mm longer than the thickness of the wall or protrude 25-30 mm on both sides of the wall. Wooden grids (lattices) should be laid immediately after laying the first layer and pressed into a monolithic clay wall in such a way that the two main longitudinal bars of the grid are pressed. This will provide a link between the first and second row wall rows. Thus, the laying of wooden meshes between subsequent rows of the wall continues with a step of 600 mm in height. Between laying the layers some time must pass until the bottom layer dries, then the next layer is placed. It is necessary to observe the technological break, it is required to continue laying each next layer only after the bottom layer of the wall is able to withstand the weight of the next lap;

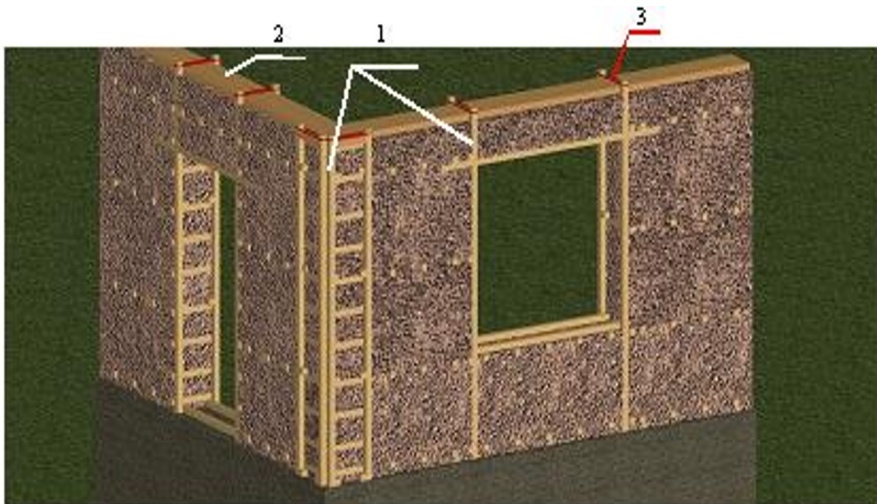


Fig. 4. Clay wall with reinforcement: 1 - vertical wooden grids, 2 - wooden anti-seismic belt.

- in places where there are door and window openings, as well as on the corners of the house being erected, vertical wooden nets are installed. The height of the wooden grid made of 50x50 mm or $\text{Ø}50$ mm bars must be 10 cm above the wall of the house to be erected;

- a wooden anti-seismic belt from a beam $h = 50$ mm is installed on the top of the wall, the width of the belt should fit between two wooden posts installed in door and window openings and at the corners of the house being built. After installing the anti-seismic belt, the ends of the two wooden vertical nets are fastened with knitting wire;

- on top of the anti-seismic belt are laid wooden beams with a spacing of not more than 700 mm and fastened with wire or nailed or stapled. On top of the beams, you can lay covers of wooden round branches or chipboard, OSB, with subsequent laying of insulating material or clay with straw. A Mauerlat made of a wooden beam with a section of 100x50 mm is attached to the beams in order to distribute the loads from the coating. Further, rafters, battens were built and metal tiles were used for the roof. The entrance door and window frames were installed in the openings;

- a wooden mesh of poles is fixed on the wall surface to the outlets of horizontal wooden beams from the wall. Then, it is plastered with a cement-sand mortar or a clay-straw mixture [11].

3 Conclusion

Based on the results of experimental work, we can state that for our country, taking into account high seismic activity, as well as numerous natural and man-made disasters, the most acceptable and reliable in terms of economic indicators and seismic resistance are houses with a wooden frame and clay filling, built according to the technology "synch" and in second place, with walls made of clay or clay materials of irregular shape, built using the "pahsa" technology. Why we consider "Synch" houses to be the most acceptable of all existing houses built from local materials is, first, considering the material capabilities of our citizens today; second, consumable materials from available materials are used; third, since specially trained specialists are not required, such houses can be built by locals themselves. These three basic requirements are of particular importance.

Reference

1. I. Arkhipov. "Mechanized production and use of adobe in rural construction" (1963)
2. I. Zh. Y. Mamatov, T. M. Tungatarov, Ch. D. Dzhumagaziev, M. Kh. Mamatova. Bulletin of KSUCTA, **3**, (2012).
3. A. T. Shapanov, M. N. Tolegenov, Zh. Y. Mamatov. KSUCTA Bull., **3** (2008)
4. Mamatov Zh. I., Dushenbekov A. D., Ilimidin u. A., Adamalieva A. D. SIT, **1**, (2020)
5. Zh. Y. Mamatov. *Modeling and experimental analysis of residential buildings from local materials*, Science, technology and life-2015. In Proceedings of materials the international scientific conference, Czech Republic, Karlovy Vary-Russia, Moscow, 24-25 December (2015)
6. Zh. Y. Mamatov. Construction of safe houses and methods of strengthening built houses (2017)
7. Zh. Y. Mamatov, Zh. S. Kojobayev, B. S. Matozimov, B. S. Ordobayev. Problems of Mechanics, **2** (2016)
8. T. R. Rashidov, Zh. Y. Mamatov. EUOS, **6** (2019)
9. A. A. Lapidus, A. S. Vorobyov. Constr. Ind., **2** (2021)
10. Patent No. 1593. Modified clay material with polyfoam (2013)
11. Zh. Y. Mamatov, N. U. Shamshiev, Y. K. Sydykov, Imanakun U. T. News of KSTU, **4** (2022)