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The Study of Derinkuyu Underground City in Cappadocia Located in Pyroclastic Rock Materials

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Abstract

Its aim is to provide a case study of the historical underground city built for up to 20 thousand people. This is a very specific, building-urban concept that is tied to the extraction of tuff rock building materials. These pyroclastic material ejected volcano in contact with Anatolian and Arabian tectonic plates. For the construction of the city were used exceptional boundary conditions. It is a fact that we have easily extractable building material which is self-supporting, and he does not need additionally reinforced. It means that these soft and stable rocks allowed the creation of large cavern system with a complete infrastructure that needed this underground city. It was placed in it both the living area and warehouse, educational, religious, wells, ventilation systems or stables for animals. There were in the in Cappadocia region up to 36 cities. The exact number depends on the classification criteria that were used.

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Keywords: underground city; tuffs; caverns; infrastructure

1. Introduction

Derinkuyu is an excellent example of the historic town, built in the subsoil in central Anatolia (Fig. 1). Its spatial range is incredible he had a capacity for up to 20 thousand inhabitants. The entire underground system has up to 18 floors while the depth of the deepest floor is up to 85 m. This historical city was discovered relatively recently in 1963 when the reconstruction of either house was made. It was opened to visitors in 1969 [7]. Underground spaces were used until the 19th century and then forgot about them. Time of origin is not precisely dated. It is only known that it was used in past centuries. There are many theories. Many authors date its origin to the period of the Hittites. Constructional attraction is that the city has only one main entrance which is also protected by a large circular stone

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with retractable system. It means that his defence has been very effective because defending a narrow hole was relatively well realized. Openings having larger area would be substantially less protected.

If we think about the development of architecture in the future so it is evident, the demographics in the future will increase the need for building underground cities that will become part of the city lying on the surface. This is already the current state because most of the world's cities have an extensive system of underground structures. Requirements in time will increase further. This presents greater demands infrastructural, environmental, capacitive, and more. It will use a series of underground technology in underground cities, and many of them will become more urbanized. Utilization of underground space is still a hot topic because of the increasing occupation of the surface areas. As shown in the publication [14], [12] and [3], [4].

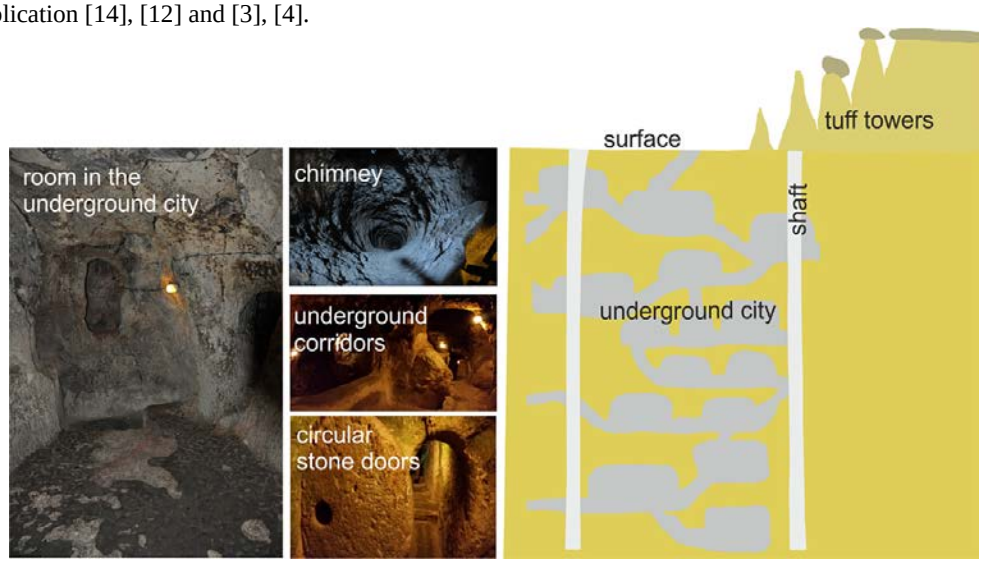

Fig. 1 General scheme for underground city of Cappadocia.

2. The character of buildings in the underground city

In the underground city there is a huge amount of different objects. According to both their size and depending on the purpose. In terms of size there is quite tiny caverns in which they were placed the tomb. While there is a huge cavern where it was school or a religious place of social gathering rooms, bedrooms, kitchens, bathrooms, stables for animals, water tanks, caverns collecting for water wells, food storage, wine, separate tombs and burial place, weapons depot (Fig. 2).

Fig. 2 General scheme for underground city of Cappadocia.

But there are also quite specific objects that we do not find in cities built on the surface. That's objects are ventilation shafts, connecting tunnels etc. It is obvious that Derinkuyu is among the largest underground cities in the world. It also represents the greatest concentration of underground cities in the world. The individual floors were mutually interconnected opening doors. Stone circular door can be opened only from the inside for security reasons. Underground spaces in Cappadocia also dealt [5] [8].

3. Concept of the underground city

Concept of the urban centre was very well developed relative to its age (Fig. 3). The most important system of the town existence is to create a self-propelled air conditioning. There were discovered more than 50 ventilation shafts. They were designed to allow air to circulate by itself. The whole system was designed so that all of the lowest and the most remote parts are sufficiently ventilated to ensure the necessities of life.

In the Kaymakli there is situated another large underground city. It has been discovered recently and its underground range is even greater. Simultaneously these underground cities were connected to each other; the distance between them is 9 km away. Cities can be connected with other underground cities. It is assumed but not proven. From the viewpoint of public supply of food, it has been shown that there were animals, especially cattle. It is a mystery how it was obtained a feed for cattle. It is clear that animals receive food from the surface. However, it must be dangerous for the safety of the underground city.

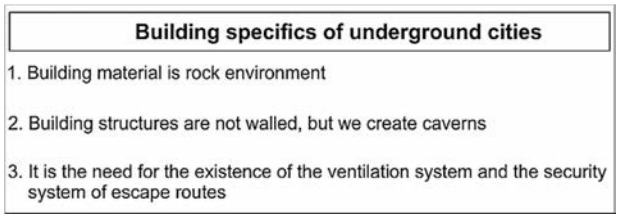

Fig. 3 Building specifics of underground cities.

4. Reasons for construction of underground cities

The basic boundary condition of building underground cities was conditions of safety (Fig. 4). It obviously varies with the military and technological capabilities of various civilizations in the historical period. It means that in the past people were hiding from the raids horses and infantry armies. Currently, underground safety protection is aimed against nuclear and other bombing attacks. Only subsequently, it is aimed against the attacks of the two opposing parties. The primary advantage is obtained at the beginning. People can hide before the enemy while they are not easily accessible to them. Safety underground cities are not fully secured. During the unveiling of potential enemies also occur certain security risks that other buildings do not have to deal with. These include the possibility of flooding of underground space, gas attack etc., security problem with the ventilation system (fume or other gas contamination). There is also the issue of starving the population and so on.

Another reason for construction of underground cities is the need to reduce the occupation of surfaces. With increasing pressure on the occupation of surfaces, there is a greater need for construction of underground cities. But building of the underground city does not automatically mean that these underground cities will no longer be a need for annexation of surfaces. There is a rule that the bigger, more extensive and deeper underground city, the greater the pressure on the occupation of surfaces. It is evident every underground city needs some kind of service on the surface.

The third reason is the need to reduce the energy demand for heating. Given the climatic zones of the planet earth, there is a structured energy need for heating or cooling the living space of people. The greater the difference between day and night temperature demands for heating are higher. In the climate zones with lower temperatures in the winter, this requirement is automatically higher. Underground space provides us a relatively constant climate environment during the year. The whole process leads to a reduction in energy intensity living space. In the underground cities we can better realize low energy buildings. Location of structures beneath the surface is better insulates from the surface temperatures. Fourth grounds are to reduce the noise pollution of cities. It is obvious that the city due to the number of machines and other mechanical devices generate high noise levels. This is a significant problem of big cities. They reduce the noise problem for cities by placing a series of noise-intensive facilities to underground and also the spatial separation places of the operations from each other. The existence of underground cities used in the education system, in terms of underground construction and many other sectors [13] [2].

The fifth reason is the reduction of the dust load cities. For surface-located cities should be placed demanding operations to dust in the underground. Direction and control of air flows is technically more manageable.

The sixth reason involves reducing the environmental burden on cities. The larger the space underground cities in the environment, there is a greater possibility of reduction of environmental burdens cities.

Another reason for the implementation of underground constructions is high demands on transport. The increasing population on the surface complicates transportation, which is becoming untenable. It then follows that we need locate these buildings into underground spaces.

The eighth reason includes the need to reduce time to move people into work and residence. This need in big cities is unable to resolve any way other than placing the infrastructure into underground spaces.

The ninth reason is the effort to preserve the existing historical, cultural and architectural values of cities. It is necessary to build a new part of the city into the underground if we want to preserve historical urban areas and at the same time in their life and work. Utilization of underground space is shown in numerous publications [11].

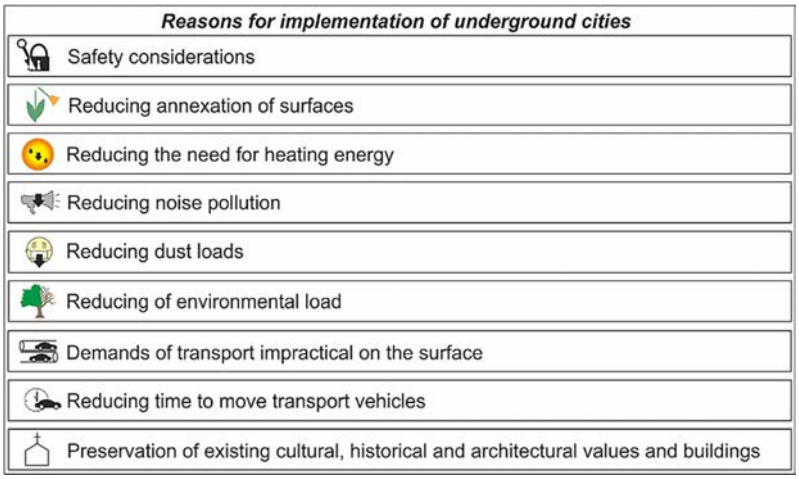

Fig. 4 Scheme - the reasons for construction of underground cities.

5. Boundary conditions for construction of underground cities

Boundary conditions include construction of underground cities in particular geological conditions, of excavation selected technology (technological options excavation) and the technological possibilities (TEB - technical equipment of buildings) (Fig. 5). Economy of the underground city is essential for its development [9] [21].

Geological conditions are determined by geological structure of the rock massif. This predisposes the character of the geotechnical properties of the rock from which the excavation of rock is the most important property, workability of rocks and compression strength. To build towns is appropriate that the hardness of rock is not too high. That was the reason for building a city Derinkuyu because it is built in easily exploitable pyroclastic rocks, respectively in tuffs. On the stability of geological environment affecting endogenous and exogenous processes. This is stated in the publication [20]. It is also necessary to rock mass was stable against collapse. This is to prevent collapsing overburden. Also important are hydrogeological conditions. This is because of the potential flooding of underground structures. From this perspective, the best option is that there is not water. In the event that there is water thus it needs to be pumped. But we also need to see to it that the change of hydrogeological conditions not destroyed water supplies and it did not cause contamination. The suitability of the geological environment as the foundation soil was examined in the publication [19]. It also includes fracturing the rock mass which is due mainly tectonic affecting the rock mass. Important is the size of fault of rock, orientation, length, surface, etc. The characteristics of the geological environment are also examined in the publication [1]. Realization of excavation and its current capabilities is another boundary condition the building of underground cities. We must choose the method that is economical but does not violate the

stability of the rock mass. If the geological conditions were worse in terms of stability, then the selected method of extraction must be sufficient to reinforce and ensure the newly created cavities.

Technological capabilities TEB (- technical equipment of buildings) are another very important boundary condition for implementation of underground cities. It means that underground cities are more difficult than the surface structures. It is about the security of air conditioning, heating, electrical, water, sewage etc. This study continuation of previous studies [17] [6] [10] or [18].

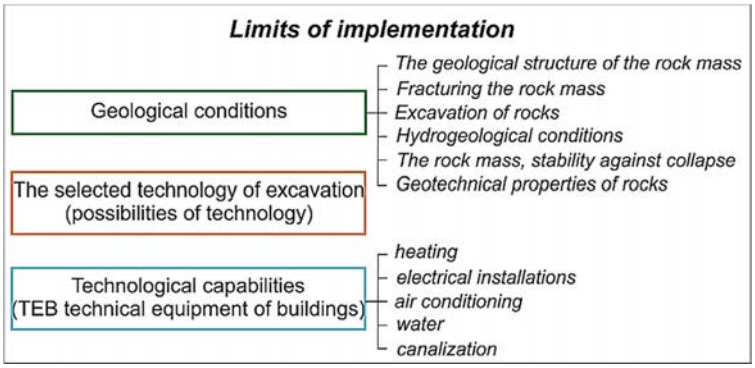

Fig. 5 Schematic diagram of boundary conditions in building underground cities.

6. Conclusion

Underground cities represent a very special environment, from several points of view. The character of these buildings is evaluated in terms of the size of individual caverns. It is a small-sized cavern where the tombs are located to the caverns of large dimensions, which were used for social purposes, such as school or religious places. Furthermore, there are areas of the shaft and connecting tunnels. That represents entirely specific functional areas.

Another point of view is the conception of the underground city. It was in the underground city very well developed. The existence of dozens of ventilation shafts allows for good air circulation. The underground cities were connected to each other simultaneously. In the underground cities were not missing also space for breeding of domestic animals.

It is also important reason for construction of underground cities. The basic boundary condition their construction accounted conditions of safety. It is an environment that provides an excellent shelter and protection from potential enemies who are unaware of the existence of the city. However, in unveiling there are plenty of risks that arise and pose a threat. These risks exist only in underground structures. It is the flooding of underground space, gas attack, the problem of starvation, etc. The advantage of realization underground cities also eliminates occupation of surfaces that can be effectively utilized for agricultural purposes etc. Of course, in connection with the excavation of underground structures is needed to determine occupation of surfaces. They also reduce heating energy, but this is also related to the climatic conditions in which the city is built. In the underground is also eliminated noise pollution of cities.

From the perspective of industrial operations may be situate their space into the underground advantageous to reducing the dust load in cities. This also applies in the context of environmental stress in cities.

Placing infrastructure into underground spaces reduces the cost of transportation, but also reduces the time to transfer the population. Transportation and traffic in the underground were quite different from terrestrial cities, generally possibilities and principles of transport deal [15] [16]. Emplace into the underground also helps to maintain the existing historical, cultural and architectural value.

Boundary conditions the building of underground cities are quite specific. It is a geological condition, the choice of excavation technology and technological possibilities. Geological structure is important from the viewpoint of excavation of rocks, workability of rocks and strength of rocks in uniaxial compressive. Hardness of rocks cannot be too large simultaneously it must be a stable rock mass. Favourable must also hydrogeological conditions, resp. protected against flooding and water contamination.

From the viewpoint of realization of excavation technology is an important option that should not disturb rock mass and thus interfere with its stability. These objects are much more demanding on the security of air conditioning, heating, electrical, water, sewage, etc.

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