Proceedings of International Structural Engineering and Construction
Holistic Overview of Structural Design and Construction
Edited by Vacanas, Y., Danezis, C., Singh, A., and Yazdani, S.

ISSN: 2644-108X

STRUCTURAL CONCEPTS IMPLEMENTED WHILE SURVEYING BUILDINGS OF HISTORICAL AND CULTURAL SIGNIFICANCE

MIROSLAV TODOROV and MIHAIL TODOROV

Structural Design Ltd, Sofia, Bulgaria

The study of cultural heritage is a multidisciplinary challenge. Working in this area meets a number of peculiarities, which put emphasis on a full study of the elements of the natural environment, as well as the need for brilliant techniques of construction to be used. The detailed studies of the monuments characteristics in a series of engineering areas over the last decade have led us to the conclusion that the creators of these monuments have achieved an important characteristic of their creations – securing their durability. From an engineering standpoint, the examples are valuable in terms of materials as well as the choice of a structural solution as their most important feature. In several sites with world cultural heritage status - the conservation and impact of the monument in the perspective of eternal longevity have been studied, while analyzing construction and the overall vision of the builders to the specific creation. It is these aspects that are the subject of research and it turns out that their role in preserving the monument is extremely important. This publication examines two monuments with extremely distinctive characteristics, requiring complex engineering research and thorough knowledge of natural and anthropogenic materials and their application in the construction techniques of the past. This is an example, and a basis for adequate solutions with an approach for long-term preservation of the structures.

Keywords: Cultural heritage structures, Engineering research and constructive treatment, Thracian tomb, Odrysian tomb.

1 INTRODUCTION

The previously surviving structural achievements of the past are a delicate area that has always fascinated mankind. The civil engineer finds in the monuments both the cultural side of man and the public system (archaeological research) and the efforts that its creators have invested to perpetuate their existence and work.

The three most important research elements (Affelt 1993) of historical importance should be addressed:

- Study of the form (structural molding);
- Type and condition of the materials (changes in them);
- Reliance on the working mechanism of the building.

It has a lot of possibilities and within the first element we need studies in the following areas:

- Topographic features – researches with validated geodetic and photogrammetric methods, three-dimensional scanning and small-scale measurements of details;

- Climatic studies and changes in climatic factors accompanying the life of the building;
- Hydrological research and assessment of the influence of the factors on the monument;
- Engineering studies with reliance on the scars of anthropogenic (negative) influences.

The second element:

- Geological structure, type of materials and their properties (stress-strain diagram, water permeability, capillary rise as a function of the grain size and mineral composition, etc.);
- Surface water and groundwater with a focus on their migration, species of migrative minerals in both underground streams and leachates from the surface;
- Harmful for the building monument processes, as a product of natural ground movement.
- Type and condition of materials, physical and mechanical properties. Material samples of different zones in a retrospective plan (depth of carbonization of solutions, weathering of rock and ceramic materials, digenesis of secondary migrants, etc.).

The third research element implies the most widespread use of the creative engineering knowledge, because through it we can chronologically observe the three significant stages of the life of the monument – preparation for construction (through the purposeful choice of place and materials), construction (technique, structural scheme, defects and damage) and continuous well-being with the clear purpose - preservation. In this publication from an engineering point of view two artistic and architectural monuments, located in Bulgaria, are considered.

2 STRUCTURAL RESEARCH OF THE TOMB AND MOUND IN ALEXANDROVO

On 17.12.2000, during excavations of the mound "Roshavata Chuka" Georgi Kitov discovered a Thracian tomb (Figure 1). What makes it unique are the colored frescoes, which for now are without parallel. The lack of a comprehensive poly-disciplinary program has led to separate, untoward construction solutions, unrelated to the complex issues for preserving the value and ineffective measures in connection with the provision of the technical elements (inappropriate planning and lack of development events, an inappropriate and technically unfortunate surrounding gallery, long-standing lack of air conditioning, lack of monitoring of the state of the structural substance and artistic values, lack of systematized documentation, etc.).

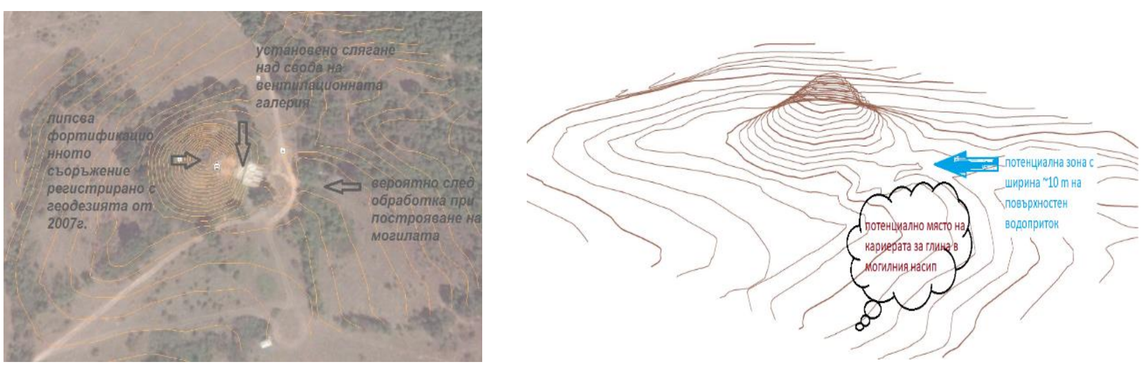

Figure 1. Situation and a model of the terrain of Roshavata Chuka.

The relief of the mound and the loading at the top, left from an old excavation for military purposes, in 2015, created conditions for the retention of atmospheric waters and the conduct trout water directly on the burial chamber, the Dromos and the newly built gallery. At the time of the examination in 2017 this form was retouched, and the topography of the tumulus resembles the conical shape, but the time has left its mark (Figure2).

Figure 2. Vault and entrance to the camera.

Due to the calm relief, the granite is subjected to weathering and the weathering zone is of considerable thickness – from 1-2 to 4-5 m. As a result of the weathering, the feldspars are turned into clay minerals, which is why the strong connection between the quartz grains is disturbed and the rock turns into coarse uniform sand without compromising the primary structure and texture of the rock. The foundations of the tomb's building are located on the upper part of the erosive mass.

The tomb is made up of well-treated quadrae of different sizes, represented mainly by the volcanic Riodasite and Riolidae tuff. Vitroclasts are the main constituent of the scales and are in the form of low-rounded particles, partially altered into zeolites and clay minerals. The ceiling of the dromos is covered with gneiss plates about 1-1.5 m long and up to 10-15 cm thick (Figure 3).

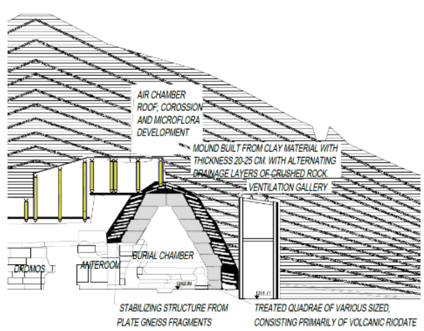

Figure 3. Longitudinal section of the tomb.

On the basis of the field research and analysis of documentation are covered the engineering features of the substance, which include:

- Situational decisions of the tumulus;
- Hydrological conditions of the site;
- Anthropogenic influences:
- Geological analysis of known data and conducted in-situ surveying;
- Structural mapping and its defects registration, consequence of the development of microflora in the ventilation gallery.

From the analyses of the identified specifics, we draw the following conclusions:

- The ground-base of the Tomb and the mound on the extract of the granites is a condition for good drainage of surface waters and in the original construction they did not reach the burial chamber and slightly affected the Dromos. The construction of the burial structure uses a constructive scheme of an ovoid type chamber and a flat scheme of the Dromos. The gravitational influence of the mound in this system is formed by fully compressive state.
- The most significant effect on the monument was the anthropogenic effects. In this group they refer to the mound top being affected during WW1, the first excavation in 2000, construction of a ventilation gallery, ditches, felling of vegetation on the surface of the mound, etc. Gallery failed to ensure a controllable microclimatic environment in the already compromised physic-chemical situation of the historical environment. It has shortened the access for surface water to the chamber, removed the original load, created a carbon-migration environment, acidification of the semi-tuff materials (development of microflora) and presence of permanent condensation on the structural elements.
- Two sets of models for analysis (Hoek *et al.* 1995) of the stress strain state of the systems and materials are formulated for the evaluation of the working mechanism, through simplified models and by the plane and spatial model (FEM) of the system. Analyses were carried out to assess the stress strain state of all elements, including those of the steel structure of the gallery. From an engineering point of view, the construction activities carried out so far and the interventions in the work of the whole facility are without a clear concept, as a result of which processes have developed with clear signs for the disintegration of the two main components – Tomb and Mound.
- At this point the monument is threatened by seismic impacts. In the original solution, including full integrity of the two elements, the buried internal structure is not threatened by seismic actions (no previous seismic defects). This is confirmed by new analyses in which the stress state in the structure does not change with time.

With violations in the historical microclimate of the tomb, threats are extending on the artistic value. Here the authors turn their attention to the fact that every element surviving until today is a valuable miracle and one-sided reading of defects – harmful.

3 RESEARCH OF THE TOMB “MAL TEPE” NEAR THE VILLAGE OF MEZEK

The Odrysian beehive Tomb dated to IV – III BCE is a magnificent architectural creation with unmistakable cultural value and public significance and is one of the largest and representative Thracian tombs of the Mycenaean type, discovered on the Balkan Peninsula, with a rich planned scheme, built with impressive construction skills (Figure 4). From the inspection in 2017 and on base (Filov 1937), emphasis should be placed on several key aspects:

- Archaeological researches were carried out as early as 1931, but until now the tomb is preserved in its authentic environment-under an imposing mound. A disturbance in the embankment is found only in the area of the current entrance;
- The tomb has a complex planned scheme - a long Corridor (Dromos), two anterooms with rectangular shape and a round chamber. Six funerals were found, which is the reason for secondary building interventions in the past;
- The tomb is built with remarkable construction skills – from large rectangular stone blocks of riolite and riolite tuff with a well-treated surface, lined precisely on a dry fugue, without mortar and interconnected with a long iron and oak brackets. A special impression makes the Beehive Dome, built in Mycenaean building tradition;

- Until now the tomb has preserved its structural stability and this fact is predetermined by the almost complete preservation of the mound;
- Traces of dilution of the structure at the inlet of the Dromos have been identified. The causes of these processes are the long-term horizontal deformability of the mound body and the human intervention when opening the inlet.
- The entrance of the Thracian beehive Tomb in its authentic form was shaped by a stone slab and the rest-blocked by stone blocks.

Figure 4. Dromos and interior view of Riolite Quadra in Dromos.

The current entrance does not reflect the original decision of the last period of use of the monument (Figure 5). This coincides with the B. Filov study of 1932, according to which a well-formed input structure existed at the entrance to the Dromos. It has performed a counterforce function in relation to the construction of the Dromos and with its dropping horizontal strain in the masonry has developed. The movement is also stimulated after opening the tomb and removing the mound body. After this period, erosion was developed, which in recent decades has declined from the self-forested surface of the mound (unlike the Naked Mound in 1931).

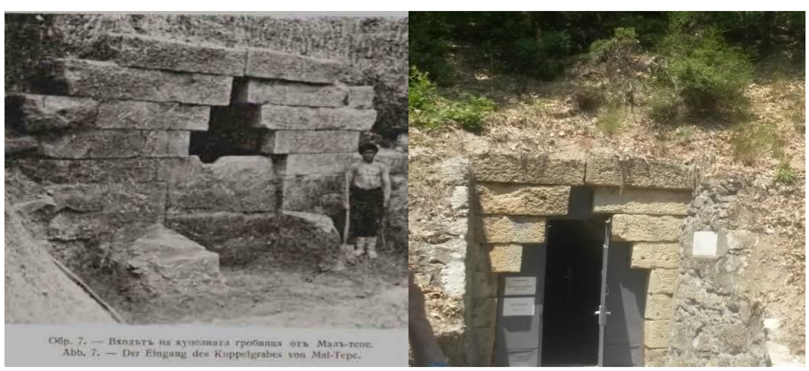

Figure 5. Entrance to the Dromois – left (b. Filov-Notices of the Bulgarian Archaeological Institute volume XI from 1937 years), right-2017.

Preliminary computational analyses, with and without creep detection in the mound, have shown that the structure is not threatened by abrupt changes in strain conditions, including seismic effects. From a structural point of view these peculiarities are directly related to the shape and construction technique, demonstrating that even the partial removal of a bulk body of the mound would lead to a number of negative consequences related to the redistribution of the forces in the masonry and the slippage in the contact between the individual frames and vaulted blocks. Our findings focused on the use of techniques for minimal and delicate intervention for conservation by storing the burial structure in its authentical visage – together with the mound.

In the future researches are planned for studying the development of erosion processes in the mound body, which is in direct contact with the building of the Dromos. The second measure is related to the detailed study of the materials in the Quadra structure, especially in the highly ventilated areas, in order to assess the degree of carbonization of the rock materials. This study will clarify the fragility of the elements and especially their surface area. These peculiarities, among other studies on the developing flora, may place requirements for isolation of the monument from free migration and of gas fractions.

4 CONCLUSIONS

The study of the current constructive condition is a vital element of the preservation of the structure of cultural heritage. The developing changes in materials, accompanied by processes of erosion, corrosion, diagenesis are prerequisites for destructive processes and risk loss of the monument. Engineering studies have the task of defining the influence and the rate of development of natural processes in the structure by registering the current signs and thus creating an opportunity for a prospective assessment of the future condition. Due to the generally complex nature of the problems, consideration of the structural point of view thought important is only one aspect of the conservation problem.

The proposed measures for design solution aim at preservation (prevention of collapse) of cultural value, improvement of the working mechanism (with a delicate approach following that of the authors) and observing the principles of durability. The preservation measures require the development of the following important aspects (Todorov 2013):

- Reliability of engineering studies with a thorough analysis of the poly-disciplinary information – archaeological research, microbiological research, material research, environmental factors, geological features, geotechnical analysis, climatic factors, etc.;
- Removal of previous measures for conservation of the monument that are harmful.
- Preservation of all elements meeting the authenticity criteria (shape, structure, material, visage) as defined by the Venice Charter.
- Strengthening by using the original technique in order to preserve the authentic mechanism of the structural scheme. Any change in the mechanism of operation potentially leads to destruction in the future.
- The long working construction needs time to react and prognosis of the durable deformation behavior of the structure is part of the model analyses, which increase the reliability of the prediction and are a basic prerequisite for structural conservation.

References

Affelt, W., *Suggestions About Technical Heritage Routes in Gdańsk*, International Seminar on the Preservation of Industrial Heritage – Gdańsk Outlook, Final Report – English Version, Gdańsk, May 11–14,1993.

Filov B., *The Dome Tombs in Mezek*, Notices of the Bulgarian Archaeological Institute, Volume XI, 1937.

Hoek, E., Kaiser, P. K., and Bawden, W. F., *Practical Rock Engineering*, Б. Филов , Известия на българския археологически институт том XI от 1937 год, 1995.

Todorov, M., *Constructive Solutions to the Conservation of Cultural Heritage*, International Conference on Case Histories in Geotechnical Engineering, Chicago, Illinois, 2013.