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Constructive Solutions to the Conservation of Cultural Heritage

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CONSTRUCTIVE SOLUTIONS TO THE CONSERVATION OF CULTURAL HERITAGE

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ABSTRACT

Bulgaria is a country with rich historical heritage and cultural diversity. The protection and conservation of cultural and historical monuments is vital to preserving the national identity of Bulgarians, the relationship with the land and traditional culture as an essential part of his life and means of survival. It should be noted Bulgarian modest contribution to the preservation of 7 (according to UNESCO) cultural monuments and two nature reserves listed as World Heritage.
In the center of the Bulgarian capital - Sofia are located over 1400 cultural and historical monuments that highlight the civilizational and cultural outlook of the capital of Bulgaria. In terms of its rich heritage Sofia has a unique resource of complex nature, characterized by:
High cultural value of individual layers historic and outstanding examples of architectural and building ensembles of the era of ancient and medieval periods, and samples of construction and architecture of the nineteenth and twentieth centuries;
The rich historical stratification of the environment is predetermined by the interaction between the West and the Orient in a European cultural crossroads, expressed with style, religious and ethnic pluralism.
All these features and wealth of construction periods and techniques pose specific requirements on construction techniques for decisions on conservation and restoration.This work presents some specific construction design in terms of approaches that resolve fundamental problems. These approaches are supported by rapidly evolving technologies in the building using various composite materials, taking into account the specific requirements of the treated material.

INTRODUCTION

Preservation of cultural heritage in the spirit of its inestimable treasure it puts many demands on the work of the structural engineer. The complexity of developing problems requires a broad view of the behavior of the building structure.

Rich variety of building techniques, related to cultural diversity, sets a range of specific features and requirements for the construction solutions. The knowledge and experience of the civil engineer covers various building materials (which are not much different from those used in the past) and technological methods, as well as the possibilities of research and modelling of elements and whole structures.

The immovable monuments hide numerous possibilities and building techniques, create suitable, as well as curious solutions. Matter of interest in civil engineering are not only traditional design solutions, but also composite solutions, which combine existing and new elements.

In the large part of the available substance, representing immovable cultural heritage, the problems are related to specific behavior of the some elements of the structure. From the point of view of the present building culture, some of the oldest solutions are already forgotten and their principles seem almost mysterious. Is this really so? Of course not! We people tend to forget and with the dynamics of our life the mystery of deciphering of the building construction grows deeper.

The modern calculation studies, research, analytical and calculational models give the civil engineer a chance to describe and explain a number of phenomena, occurring in the building constructions. In this kind of objects the defects and flaws are a retrospection of the processes, occurring in these structures with time. The analytical methods give the experienced researcher additional opportunity to explain and find adequate solution, with which to slow down or minimize the impact of the harmful processes. This research paper

presents a few simple models, used for description of repeatedly occurring defects and flaws in building constructions made of masonry materials.

SPECIFIC PROBLEMS

Until today are basically reserved buildings with religious and public function. Even from the ancient times such buildings present us with various building techniques and impressive scale. The specifics of their architectural substance most often is related to elements of religious, fortificational and public constructions. Their function determines their scale and degree of preservation. All known and forgotten today building techniques can be reevaluated in the context of the new materials and the modern knowledge about the behaviour of the constructions, especially the behaviour of dispersion media, which can be successfully analyzed by the new modelling techniques of the mechanical engineering.

The main structures problems of the archaeological substance are generally connected to long-term processes of erosion and corrosion, aging and decay, which in their turn are specific markers and give an opportunity to evaluate the structural behaviour, as well and the change of material properties. These specifics give the engineer an opportunity to form a concept of the long-term behaviour of the constructions.

These facts are especially important for the analysis, evaluation and adequacy of the design solutions in the project development and help to predict the behaviour of the reconstructed elements in the future.

The foundations as primary element usually are the most typical reason for destruction of immovable monuments. The foundations in the ancient and medieval monuments are developed as stripes from dry masonry. Mortar, lead brackets and clay substances have been used in some of the monuments. Masonry materials consisted of rough, as well as processed stone (Fig. 1).

(a)

(b)

Fig. 1. View of basic wall

The processes in the foundations are caused by relatively long-term deformations, developing in the soil. In their turn, the foundations are the main reason for the damages in the masonry structure elements and key details.

Continuous exploitation of a large part of religious and fortificational buildings has led to numerous reconstructions and additional building. In most cases these reconstructions are substantially different from the original masonry and even more often are not properly implanted in it (Fig. 2).

(a)

(b)

Fig. 2. View of naos (sanctuary) of an ancient temple - addition of secondary building elements

The second most common reason for destruction is the erosion, caused by climatic factors. The substance has been exposed to intensive sun heat and freezing, as well as constant attack of atmospheric waters, which contain numerous chemical substances, mostly CO_2, which are the main reason for erosion of stone materials, used in the masonry. The mortar undergoes substation transformations, related to climatic conditions and mainly carbonization of $Ca(OH)_2$.

Another feature of the substance is the relative instability of the masonry, caused by the connecting substance and the specifics of the stone walls. Usually the stone walls have been built with two frontal sides and filling, made of connecting substance and rough small stones. This feature in particular, in the absence of fortifying grills is the main reason for the splitting of stone masonry. These damages are strongly manifested when the stones are not properly aligned. Clearly observed in the constructions with religious purpose is another feature of the foundation laying and it is related to consecutive layering of different building periods. This vertical alternation sometimes amazes us with the resourcefulness of the builders and the diversity of the building techniques.

(a)

(b)

(c) *(d)*

Fig. 3. Characteristic cracks and damages in masonry

On Fig.3 are presented some of the most characteristic defects and damages of masonry structures. Fig.3a illustrates a particularly interesting crack in a church dome as a result from vertical seismic movements. Fig.3b shows the typical cracks in the apse of a church. And Fig. 3c and Fig.3d show characteristic horizontal displacements of the construction, resulting from continuous deformations of the ground.

MODELS

The mathematical modelling as basic tool of the modern practice is an approach which presents the civil engineer with the necessity to possess knowledge of a broad range of materials, their properties, changes they undergo with time, as

well as methods of their determination.

The second basic approach is observational. It makes it possible to evaluate the constructional characteristics and scale in order to solve a number of delicate practical problems.
The properties of the materials are studied using standard laboratory procedures. But in some cases standard procedures not only cannot help, they also require reevaluation and notable corrections. It is important to collect enough data to study the archaeological substance with the help of full-scale or numerical modelling.

This study presents two characteristic models and the results of their analysis. Through them we are looking for qualitative and quantitative assessment of stress and strength conditions and an explanation of occurring defects and damages. For modelling purposes are used different programming products. The two models presented on Fig.4 are created with SAP2000 and Plaxis. The creation of these models uses the experience of builders from ancient times to present day, reaching us with development of number of solutions.

The fact that in the past various materials have been used, such as wood, lead and copper brackets and rarely iron, needs to be considered.

The model examining a dome of a temple uses volumetric elastic elements (Solid) with the help of SAP2000 software. Through it was sought a description of the stress and strength conditions under different possible loads during the time. At first sight the presence of the crack running along its entire periphery had no reasonable explanation.

The tensioners of the dome system didn't show any defects in the anchoring zones. |The second possible assumption was that the entire vertical pivot system supporting the domes has suffered major horizontal deformations also wasn't confirmed. The research and analysis gave a picture of tangential stress along the entire periphery (cyan coloured zones on Fig.4), which surprised us and this effect occurred after the vertical component of the seismic influence was taken into account.

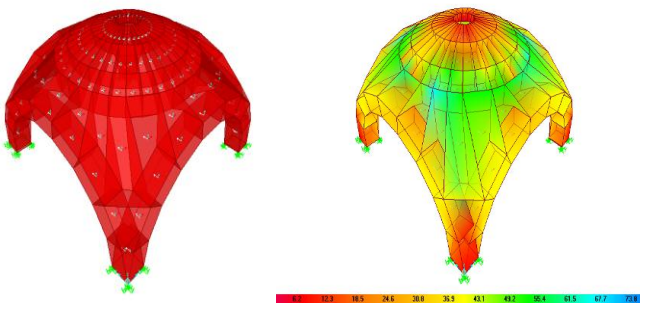

Fig. 4. Model of the dome and tangential stress distribution

The second basic defect – wall splitting, was analyzed and studied using another software product - Plaxis. The modelling of the elements was conducted using different soil models, mainly MC, HSM и JRM. These models were used in different combinations, depending on the sufficient amount of parameters, obtained in the study of the materials. The models and part of the results are presented on Fig.5. In the study of this model the zones of concentration of the main tensile stresses, which were the reason for the cracks, were clearly defined. In the zones with high tangential stresses are observed mostly horizontal displacements between two blocks of the masonry.

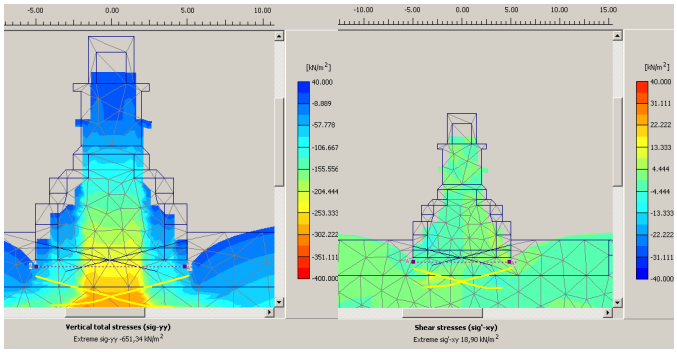

Fig. 5. Normal and tangential stresses in the structure

This two simplified models have given us an opportunity to explain the developing processes. Consequently they allowed future solutions, implemented at the moment.

SOLUTIONS

In the walls above the ground the movements of the earth base and the damages from the ongoing climatic processes are more clearly expressed. Usually because of the damaging effects above ground the base walls remain in the background.

The problems in the above the ground walls are caused mostly by the following reasons:

- Yielding or long-term deformations of the ground;
- Pendulum behaviour of the walls with big height;
- The influence of the dome effect;
- Splitting of the walls and collapse, usually on the outside facade;
- Decay of fortifying grills and tensioners, supporting the construction;

- Seeping and washout of the connecting substances, carbonization of the mortar, erosion of stone and ceramic masonry materials;
- Cracks and damages from past seismic events;
- Fires and human activity.

The constructive solutions are reached considering the numerous limitations like inaccessibility, preservation of the existing interior elements, preservation of the unstable substance, etc. In these conditions the existence of many different technological methods and constructive solutions allows to solve part of the problems. In some cases constructive reconstructions with rebuilding the walls anew, clearly differentiating the authentic from the newly built substance, is used. The fact that an unstable structure is studied in this processes needs to be considered and usually it is subject to reconstruction. In this case due to the nature of the structure of the masonry still preserved authentic parts inevitably suffer. Using this experience, the methods of the injection technics, which improve the quality of the ground base and the integrity of the above the ground wall, are employed in a number of solutions, using the well known silicate, steel and polymeric materials, often used in the hydrotechnical and mining industry. The knowledge of these groups of materials and their combinations allows easy solutions of constructional problems as well as aesthetic qualities with less influence on the substance.

Schematic diagrams for integration of new construction with the old, combined with additional fortification of the base are presented on Fig.6. This solution is used in the reconstruction of numerous (late antiquity, medieval and modern) Orthodox Christian temples and partially some fortificational constructions.

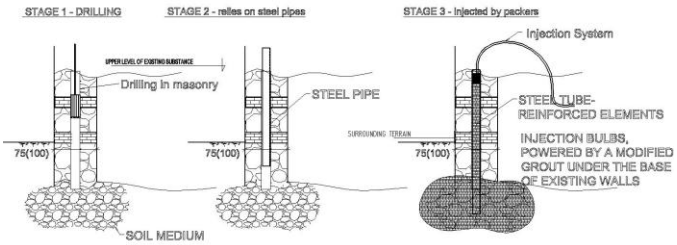

Fig. 6. Schematic diagram of injection

This technique is also successfully used with various diameter of drilling for stabilization of brick walls. It is also successful when using injection solutions, mainly polymeric and in combination with steel and fiberglass rebar. Often it was used for rebarring of highly artistic stone masonry. This technique allows the preservation of both interior and exterior sides of the substance and gives an opportunity to upgrade and conserve it with almost no noticeable effect. The modelling and study, aiming at evaluation of the constructions behaviour, are the next stage of the project process. With the potential of the professional software products and the knowledge of the characteristics of the materials these complex solutions are easily amenable to mathematical analysis.

CONCLUSIONS

The whole constructive condition of many cultural monuments presents the civil engineer with unusual problems and requires an individual and substantial from a technological point of view approach to the solution. The abundance of materials and technologies in the construction give great opportunities and in these cases only ingenuity leads to good results.

In the series of cases, for which the illustrated constructive approaches and techniques have been applied, the following advantages have been observed:

- In these cases of reconstruction the relatively stable part of the masonry is not being damaged.
- With proper testing of the chosen technique, which is a mandatory stage of implementation, the authentic architectural and artistic qualities of the substance are preserved.
- The use of this method is convenient for the rebuilding of elements that are subject to conservation and restoration.
- The correct selection of the injection solution in combination with known materials allows the preservation of the original look of the murals and prevents the secondary effects of salt condensation on the surfaces.

This area of expertise of the civil engineer is different from the conventional one, not only with the abundance of the field itself, but also with the great amount of materials and technological methods. It gives an unique chance for a different view on the mechanics of the building construction. It enriches and broadens the horizons of the civil engineer and constantly urges him to search for the rationale.

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