DIAGNOSTICS OF TECHNICAL STATE OF HISTORICAL-CULTURAL MONUMENTS STRUCTURES BY COMBINING INSTRUMENTAL AND NUMERICAL METHODS

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Abstract

In the work is developed the diagnosis of the technical state of the historical and cultural monuments structures by combining of instrumental and numerical calculation methods that is carried out on the basis of laboratory, non-destructive control methods and the creation of design models (functional or imitative) at conducting numerical experiments. The methodology of the complex approach to solving the problems related to the maintenance of resource, safety, durability and strength of the monument structure are also stated. The presented methodology envisages the creation of an automated complex in order to periodically check the technical state of the monument.

The analysis of the obtained data provides the basis for the evaluation of the technical state of the monument that provides for the collecting of the structural solution of various reinforcements in a unified base. If necessary, an appropriate amplification scheme should be selected. Finally, we will obtain an assessment of the technical state of historical-cultural monuments, by combining instrumental and numerical methods. All this will give us a noticeable technical and economic effect.

Key words: monument, instrumental examination, model, diagnostics

Introduction

In the period of global, technical, and ecological problems, the refinement and development of methods for diagnosing the mode of deformation of the historical-cultural monuments structures are especially relevant.

Cultural heritage and its material components, historical-cultural monuments - represent an integral part of the Earth's ecosystem, an informational resource of intellectual potential, the preservation of that is necessary for future generations. It is a source of spiritual food, culture, art, knowledge, and experience for future generations. The primary task, with the preservation of monuments, is the study of the given heritage and information. The modern method of assessing the mode of deformation of monuments requires the improvement of the combination of instrumental and numerical methods of diagnosis that gives the possibility to us to manage the state of the monument. It is also necessary to develop a system for the registration, collection, systematization, and storage of the received information for its analytical processing.

Based on all the above-mentioned, the problem is very relevant.

The aim of the paper is to develop the concept of perfecting the methodology for diagnosing the technical state of historical-cultural monuments by combining instrumental and numerical methods.

Main part

The historical-cultural monuments are considered as a system object "monument- environment" and include information in recent years, in the practice of restoration of historical-cultural monuments, there is a trend of complex assessment of their technical state in relation to changing environmental conditions. Therefore, it has become quite reasonable to consider the object of restoration as an element of a complex natural-technical system "monument-environment", in that architectural monument would be imagined as a subsystem, containing some interconnected structural and architectural elements.

We have made an analysis of the structural solutions of the monuments in order to carry out a complex examination of the technical state of the historical-cultural monument and to formulate recommendations in the right direction for conducting the restoration.

Based on the analysis, a classification of structural solutions was created, instrumental measurement methods were used to study the causes of damage and deformations.

In the works [1,2,3,4,5,6,7], the structural types of monuments are considered and the analysis of structural solutions is carried out, on the example of several historical and cultural monuments in Georgia, such as: Alaverdi Monastery, Tsughrugasheni Cathedral, Safari St. Saba Temple, Nikosi Church complex of the Deity, Sanagire Basilica (Gurjaani district), "Eastern" complex (Shikhiani), located on Abo-Tbileli Street #1.

Fig. 1. Shikhiani "Easter" temple

From the considered works of Georgian and foreign scientists [4,5,8, 9] it would be seen that they give preference to construct an experimental model and testing it on a vibro table, or by numerical methods, by construction of design model, processing schemes for reinforcing structures.

Based on the literature review, it is determined that conducting the experiment requires a long time and high material expenses, and the construction of the design model and the calculation using only numerical methods does not give the desired results. Therefore, we considered it is necessary to improve the existing methodology by combining experimental and numerical methods.

For the restoration-reconstruction of historical-cultural monuments, it is appropriate to consider the features of their structures and the working principles of individual elements as independent structures, determining their deformability and bearing capacity.

The features of the types of arched structures of the historical-cultural monuments in Georgia are considered, on the example of the structures of the historical-cultural monuments.

We have considered different types of the most common structures: cylindrical dome (Fig. 2), cross dome (Fig. 3), closed dome (Fig. 4) and closed arches (Fig. 5).

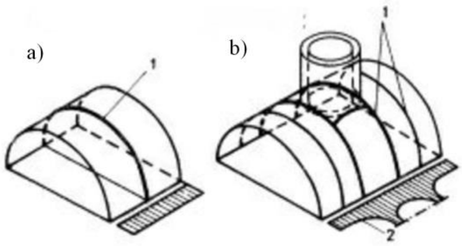

Fig. 2. Cylindrical dome

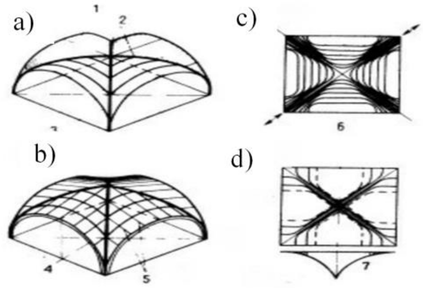

Fig. 3. Cross dome

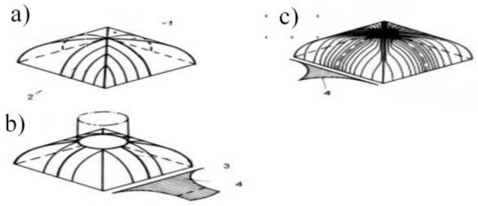

Fig. 4. Closed dome

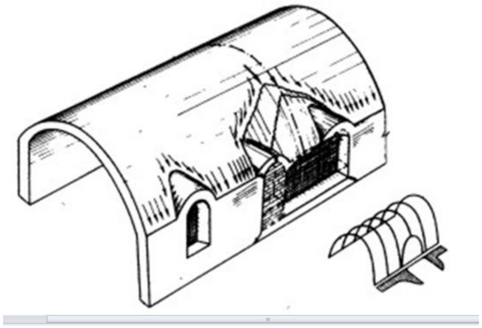

Fig. 5. Closed arches

The considered examples showed that the rigid element gives the possibility to significantly damaged arch systems to maintain their original shape for certain time even in the absence of their "supporting restraint".

The shape of dome or arch, in that arbitrary section under load works in accordance with the most rational mode, are symmetrically compressed, is the most rational shape.

In practice, most of the arches were built for technological and operational reasons, as well as from purely aesthetic considerations, are not rational. Their cross-sections are asymmetrically compressed or undergo different types of stress.

The height of the compressed zone of the cross-section is the main indicator, both in terms of stability and in terms of the arch structure ability. This applies to arches made of brick and stone. For any non-centrally compressed section, the height of the compressed zone is approximately equal to twice the distance from the point of application of the normal force to the nearest edge of the section, i.e.

$$h_c=(\frac{h}{2}-e)2,$$

where h_c - is the height of the compressed zone; h - is the total height of the section; $e=\frac{M}{N}$ - is the eccentricity of application of normal force with respect to the center of the section.

By decreasing the height of the compressed cross-sectional area, the streses increases, while at the same time the stability of the arch contour decreases. This attitude is expressed by the formula.

$$\sigma = \frac{N}{F_c \ \varphi},$$

In this formula F_c - is the area of the compressed cross-section; φ - is a coefficient that includes the off-center compression of the cross-section.

The minimum height of the compressed zone, at that the structure still maintains equilibrium (stability) depends on various factors, specifically: the value of the load and the normal compressive force N, the dome span, the quality of the construction material, and others. The design theoretical height of the compressed cross-sectional area would sometimes be controlled by measuring (probing) the depth of connecion areas.

Each type of structure is characterized by a specific type of deformation, which is included in the characteristics of the working scheme. Along with the change of the working scheme and the condition of the construction material, the deformation expression and deformability change.

The characteristic location of cracks in cylindrical, cross, and closed domes with respect to main types of arches and main types of deformations is determined.

The sensor system gives the possibility to control the increase in stress and the occurrence of deformations in the structures of buildings or the deviation of its main elements from the vertical, horizontal displacement on a defined horizon, to estimate the amount of pressure on the ground of the object, the amount of wind load on the upper levels, to control the geological and hydrogeological condition of the building base.

Exceeding the allowable operational loads or negative impacts that lead to the loss of stability of the structure will generate an alarm signal. On the diagnostic scheme, the accident zone may be allocated, and the type of impact specified.

The concept of perfecting the method of diagnosis of the mode of deformation of the structures of historical-cultural monuments by a combination of experimental and numerical methods has been developed that is presented in the form of a block diagram of hardware-computer diagnostics of the stressed-deformed state of the historical-cultural monument (Fig. 6).

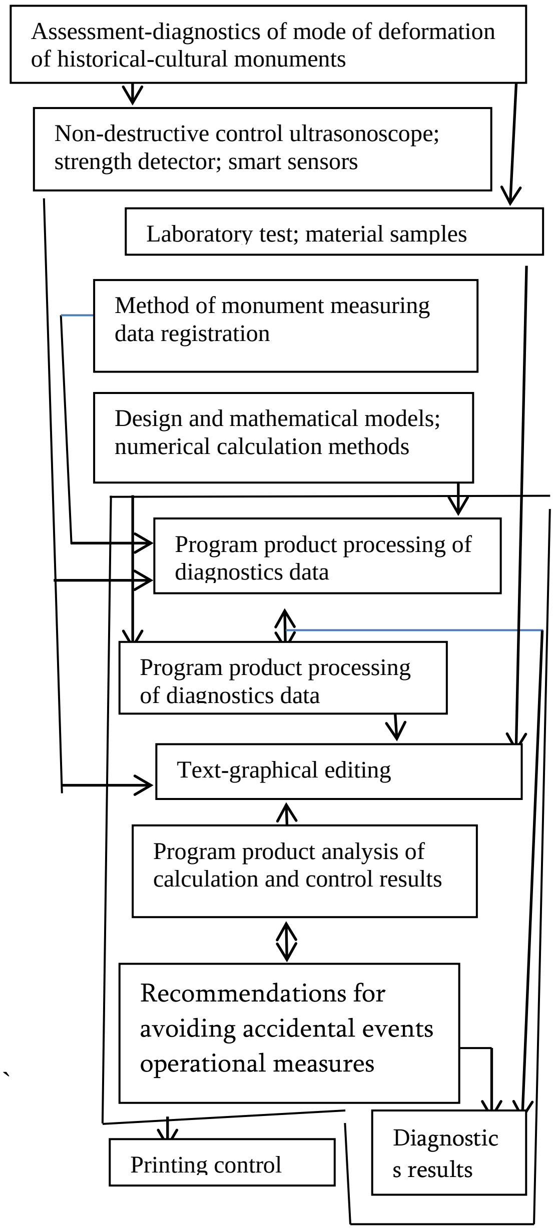

Fig. 6. Block diagram of hardware-computer diagnostics of the historical-cultural monument mode of deformation

Diagnostics of the historical-cultural monuments mode of deformation by combining experimental and numerical methods is a methodology that includes a complex of hardware-computer diagnostics and combines non-destructive, modern methods of control, laboratory testing of the used material and realization of the obtained results by numerical methods (e.g. finite element method), based on the principle of entering the received data into the reporting model.

The study of the Shikhiani "Easter" temple structures was carried out with the developed methodology. The data of the visual and instrumental examination of the technical state of the load-bearing structures are presented. After drawing up and calculating the design models of the objects under examination, the analysis of the results of the calculation was carried out, after which the enhanced model was calculated, and a comparative analysis was made. In the paper are presented both the results of the calculation and the reinforcing schemes of the damaged structure in an illustrated form, which are stated below.

Design model of Shikhiani temple and its calculation design program SAP2000 fragments

Design model of Shikhiani temple and its analysis Fragments of CAE program SAP2000

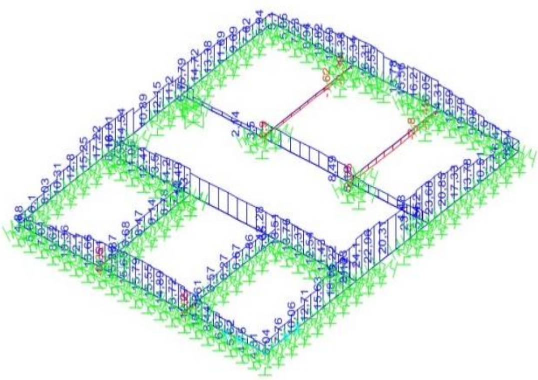

Fig. 7. Diagram of of stresses redistribution on foundation in the case of clay ground, SAP2000

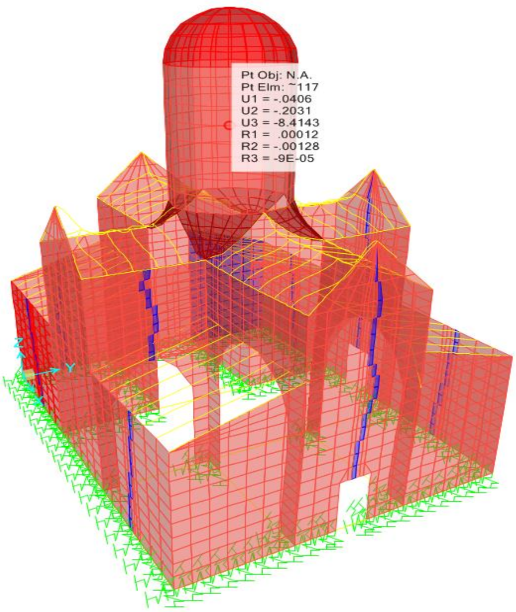

Fig.8, a. Displacements at wind load, SAP2000

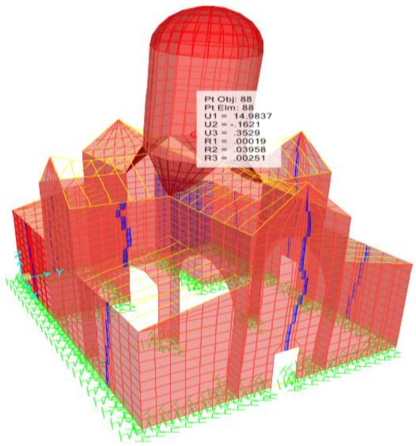

Fig. 8, b. Displacements at earthquake, SAP2000

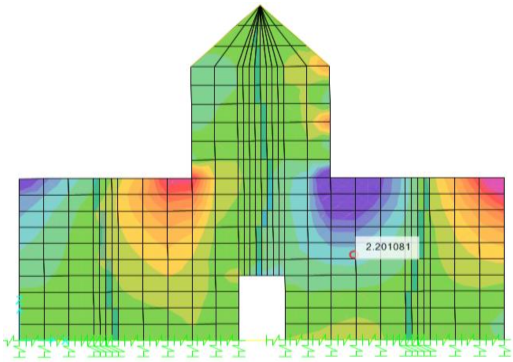

Fig. 9, a. Cracks distribution on west façade prior model reinforcement, SAP2000

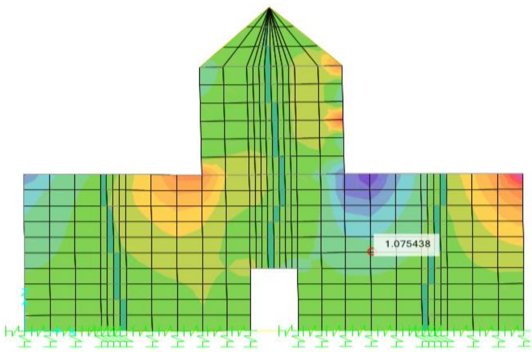

Fig. 9, b. Cracks distribution on west façade in reinforced model, SAP2000

The stress permissible limit for such type buildings is presented as 1,1, that is accepted from norms for for masonry and reinforced masonry structures (SNiP II-22-81).

On the structure (dark color on the structure, SAP2000 Critical locations are shown). From calculation is clear that stresses in reinforced model satisfy the proper norms.

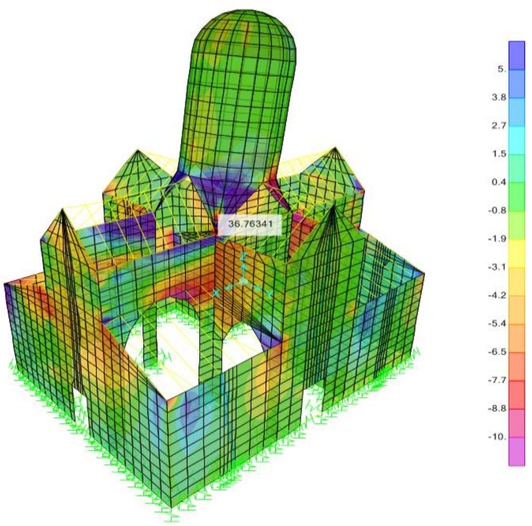

Fig. 10, a. Stresses distribution on whole structure of model under reinforcement, SAP2000

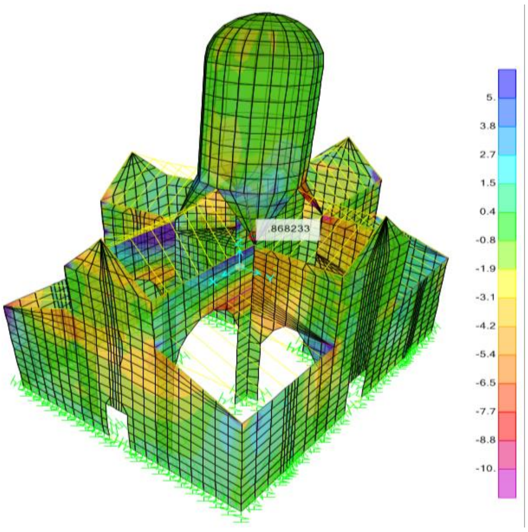

Fig. 10, b. Stresses distribution on whole structure of reinforced model, SAP2000

The models are calculated using the finite element method in the "SAP2000" program, in accordance with acting in Georgia norms. Design schemes are built according to architectural and structural projects. Permanent, temporary and wind loads are modeled on buildings and calculated according to wind pulsation effects. The impact of the seismic force on the structure is also considered, taking into account the relevant norms.

Buildings were calculated by stresses combination.

The maximum displacement obtained by the wind load for the Shikhiani "Easter" temple is 20 mm, which is permissible, considering the relevant norms, and as a result of the seismic impact, we get the maximum displacement, in value - 146 mm, which is quite a large displacement.

The analysis of the results of the calculation showed us that horizontal deformations under static load in some elements of the building are not allowed.

The analysis obtained from the results of the calculation requires structural reinforcing of the monument.

Conclusions

1. The structural solutions of the existing historical-cultural monuments are analyzed, their classification is made (for example, cylindrical dome, cross dome, closed dome and closed arches), the architectural monument is presented as an element of a complex natural-technical system "monument-environment" that contains mutual connecting structural and architectural elements.
2. The block diagram of hardware-computer diagnostics of the historical-cultural monument mode of deformation has been developed, in which the methodology of the monument state examination is provided, combining experimental and numerical methods.
3. The technical state of the historical-cultural monument - Shikhiani "Easter" temple building was studied using the developed methodology.

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