USING PHOTOGRAMMETRIC DATA FOR ESTABLISHING 3D FINITE ELEMENT MODEL OF A MASONRY AQUEDUCT

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ABSTRACT

Documentation of historic structures is very important for conservation of cultural heritage. There are various methods of documenting the historical and cultural heritage. Photogrammetry became a widespread method in architecture, with developing computer industry. In comparison with the other documentation methods, photogrammetry is faster and more precise.
Metric cameras and laser scanning are used as measurement techniques in photogrammetric method. Data collected from both of these techniques can be used in architecture. In this way, time and effort is reduced while making as built drawings in digital format. Analysis of the structure gives reliable information of the present level of structural safety of the building. One of various analyses methods used for is finite element method.
This paper will present an approach of using digital photogrammetric data in architecture to generate 3 – dimensional (3D) finite element model of Kovukkemer aqueduct. 3D point model and 3D solid model are evaluated by using photogrammetric data.

1. INTRODUCTION

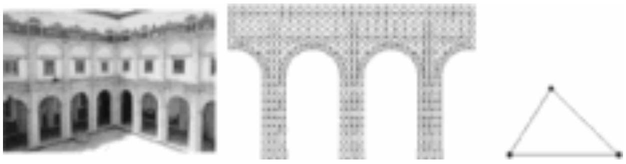
Architectural aspects of preservation and maintenance of the existing historical heritage is a cultural imperative. Aging, increased loads, exposure to aggressive environmental factors often result in deterioration of many culturally valuable and potentially functional structures. To achieve preservation in a building's historical and cultural context, diagnostic studies for understanding the causes and mechanism of decay, environmental monitoring and selection of appropriate preservation methods and materials are indispensable scientific and technical basis for correct interventions. Before making a decision on structural intervention it is important to evaluate the present level of structural safety that will reconcile qualitative and quantitative analysis.
The study of historical structures oriented to their preservation requires multidisciplinary teams of specialists and requires special technical and analysis tools adapted to the structure's geometry and building materials. For safeguarding and enhancement of the cultural heritage to future generations, documentation is an essential phase of the study. Possible tools could be the geometrical survey, the crack pattern survey and accurate photograph documentation. Geometrical survey of a structure is very important for both understanding the present state of the structure with its structural damage and material decay and modeling the structure for structural analysis.
Most historical buildings were of masonry. Analytical models appropriate to any type of masonry structure and any type of masonry as a composite are not easily implemented. Only a deep knowledge of the geometry of the structure and of its elements, of the constraints and of the material constitutive laws can help implementing appropriate models.
In general the available information of a structure is represented in plans, prospects, sections, usually in separated 2D representations. In recent years, a digital photogrammetry technique offers the possibility to transform and use different photos taken from the same object with particular objectives as fisheye, wide angle or tele objective so that sights of the object which are very similar to the real view for a human observer can be produced. Through this technique, a simplified 3D model can also be derived for structural modeling purposes.
This paper will present an approach of using digital photogrammetric data in architecture to generate 3D finite element model of masonry structures. As a case study, the Kovukkemer, a masonry aqueduct in İstanbul, was selected. The 3D representation of the complete structure was obtained by point model and 3D solid model from photogrammetric data of the Kovukkemer Aqueduct.

2. ARCHITECTURAL PHOTOGRAMMETRY

Architectural survey is useful in order to provide details on the geometry of the structure, to identify the points where more accurate observations have to be concentrated and to identify the irregularities (vertical deviations, rotations, etc.) of the structure.
This documentation of the geometry and of the state of conservation of the materials of the structure, and particular detailing should be easy to update, be accurate while using simple tools and having the possibility of including information into 3D models.
The technique based on digital photogrammetry offers very accurate 3D model of the building integrating a number of scans taken from different viewpoints with highly automated software. Images from a digital camera can be mapped onto the triangulated 3D surface model to create a photo-realistic virtual reconstruction of the building and can be used as a base for importing all the digital images or data obtained from investigations. The 3D model can be converted to CAD drawings needed to plan the investigations and the restoration actions. Data acquisition can by conventional metric cameras or laser scanning technology.

3. STRUCTURAL ANALYSIS OF MASONRY

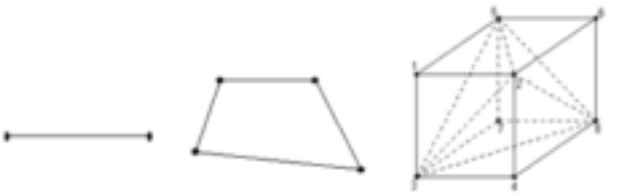
The structural analysis of a historical building can help in defining the eventual state of danger and in forecasting the future behaviour of the structure. In structural analysis, finite element method is used widely.
The finite element method essentially involves modeling the structure by dividing the body in small elements of various shapes with definite mathematic models (Figure 1). These finite elements are joined with the nodes which are corners of elements.



(a) (b) (c)

Figure 1. Definition of the structure with finite elements: (a) structure (b) finite element mesh (c) finite element

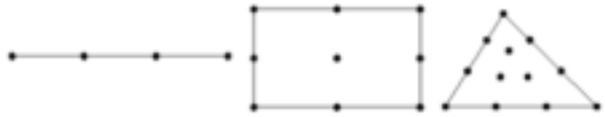
In finite element method, the geometry of the structure is idealized as one dimensional by considering the structure to be made of linear elements, two-dimensional elements as shell elements or fully three-dimensional elements as solid depending on the problem and structures body (Figure 2).



(a) (b) (c)

Figure 2. Finite elements: (a) one-dimensional element (b) two-dimensional element (c) solid element

Analysis by finite element method depends on stress evaluation of the nodes. More the number of nodes, more number of elements are used and the better approximation can be obtained. But this make the problem complex and extends solutions time. Advanced finite elements are developed to exceed this problem (Figure 3).

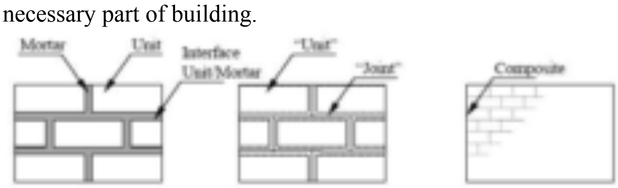


(a) (b) (c)

Figure 3. Advanced finite elements: (a) linear element (b) quadrangle element (c) triangle element

For appropriate and rational analysis, the definition of the mechanical properties of the materials, the implementation of constitutive laws for decayed materials is needed. However, the analysis of historical masonry constructions is a complex task for masonry building material is not homogeneous, isotropic and linear elastic.

Depending on the level of accuracy and the simplicity desired it is possible to use macro modeling or micro modeling approach. In macro modeling, mortar and blocks are defined as composite where in micro model these blocks are defined one by one. Micro modeling is more detailed so usually it is used on the necessary part of building.



(a) (b) (c)

Figure 4. Modeling approaches: (a) masonry specimen (b) micro-modeling (c) macro-modeling (Lourenço, 1994)

For modeling, the geometry of historical masonry structure is rather complex as there is no distinction between decorative and structural elements. Fully three-dimensional models are usually very times consuming with respect to preparation of the model, to perform the actual calculations and to analyze the results.

The geometrical 3D survey carried out by photogrammetric methods can serve as a base for mathematical modeling for elastic models as for non linear or damage models which can take into account also the surveyed crack pattern.

4. CASE STUDY

To generate 3D finite element model of historical buildings using photogrammetric data, The Kovukkemer aqueduct was chosen as a case study.

4.1 TheKovukkemer Aqueduct

Kırkçeşme water supply line is the most important water supply system of The Ottoman Empire. Kırkçeşme system consisted of two branches and there were 33 aqueducts in various sizes on it. The Kovukkemer aqueduct is one of the four monumental aqueducts on this water supply system (Figure 5,6). The aqueduct is constructed over the Byzantine ruins.

Figure 5. The Kovukkemer aqueduct

The Kovukkemer aqueduct is of three stories. The length of the main façade is 207 m (Figure 7), total length is 407 m and the height is 35 m. Stones used in the aqueduct are hewn stones in 130 cm – 150 cm width and rubble stones (Çeçen, 1996).

Figure 6. The Kovukkemer aqueduct

Figure 7. Main façade of the Kovukkemer aqueduct

4.2 Photogrammetric Data of Kovukkemer Aqueduct

Photogrammetric data acquisition of 3D point clouds with 92905 points and 2D drawings of the main façade was done by Yıldız Technical University, Civil Engineering Faculty, Division of Geodesy and Photogrammetry (Figure 8, 9, 10).

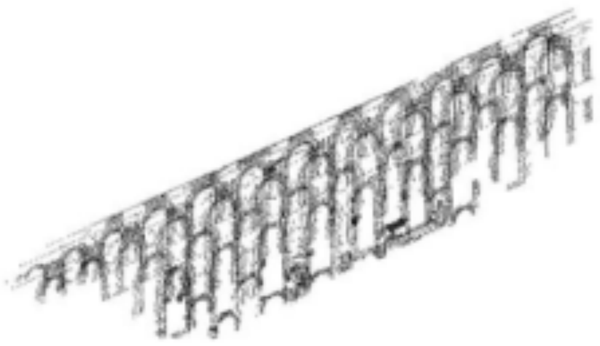


Figure 8. 3D point clouds

Data of 3D point clouds was transferred to DWG file format as drawings in Micro Station computer program. It was found that photogrammetric data constituted of points identifying the surface of the structure from two façade and omitted the cross section which is very important in architectural studies. For this reason, in surveying of this aqueduct, Restoration Division of Architecture Faculty was not able to work with Photogrammetry Division and continued their project in conventional surveying methods (Figure 11). In this study of structural modeling, this deficiency was overcome by using the cross section of the aqueduct developed by Restoration Division. The width of the aqueduct decreases from base to top.

Figure 9. The east façade of Kovukkemer aqueduct

Figure 10. The west façade of Kovukkemer aqueduct

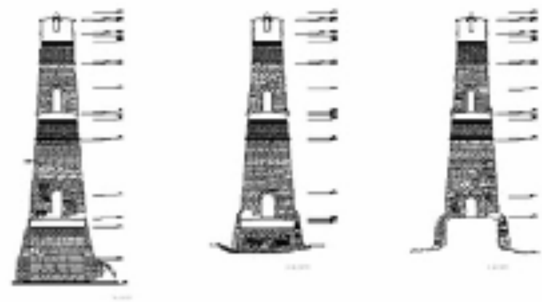


Figure 11. Cross sections of the aqueduct

4.3 Generating Finite Element Model

3D finite element model of Kovukkemer Aqueduct was generated without depending on any analysis program.
DWG and DXF file formats were used since photogrammetric data is CAD data. 3D point clouds were used for generating a model. There are 92905 points in the point clouds. While point clouds' drawings were surveyed it was observed that some of points overlapped. After ordering the points, there remained 40613 points.
Nodes are identified with node numbers and coordinates in finite element analysis programs. But in photogrammetry, such node numbers are not used for there are lots of points identifying the structure. To overcome this problem, photogrammetric data were transferred to different computer programs and "import", "export" and "save as" options were used between these programs. DXF file format can be used in all finite element analysis programs.
Finite element analysis programs automatically give numbers to all points. In Kovukkemer aqueduct, after arranging the point clouds in proper layers and importing point clouds to analysis program, numbers were given automatically (Figure 12).

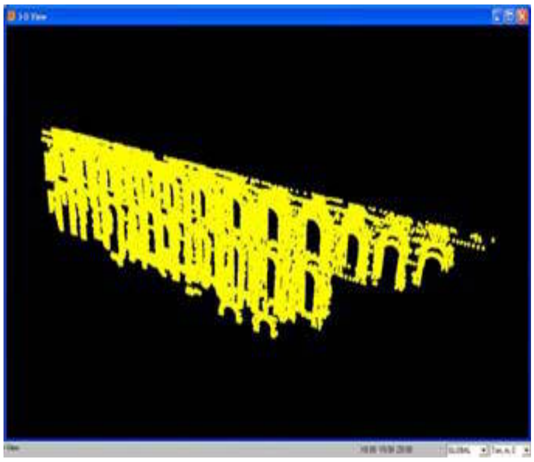


Figure 12. Finite element model of photogrammetric point clouds

In a finite analysis program, the points can be modified, copied and deleted (Figure 13). After importing the point model of the structure, finite element analysis program is able to generate finite element mesh model. This procedure can be done manually or automatically by CAD drawings in any analysis program.

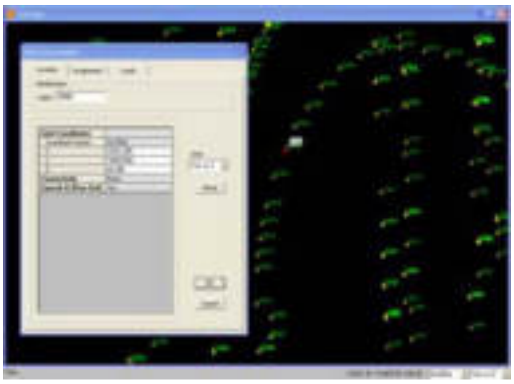


Figure 13. Point properties in finite element model

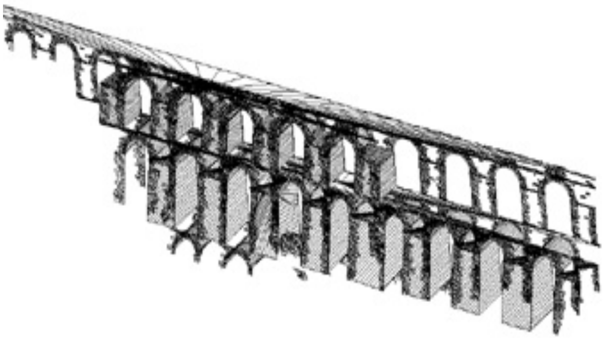


Figure 14. 3D model of the Kovukkemer aqueduct

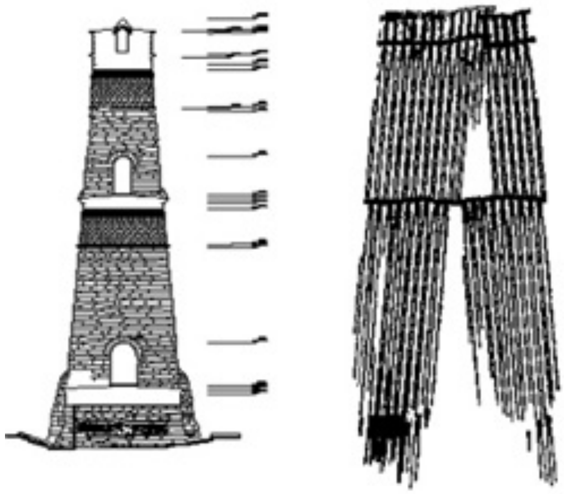


Figure 15. Arrangement of photogrammetric data related to survey drawings

Photogrammetric data drawings were arranged in layers as arches aligned one after another, bond beam at certain intervals, and masonry blocks in between the arches (Figure 14). Then with the help of the architectural cross section, these elements in different layers were tied face to face to each other forming the cross section (Figure 15). This model can be used for macro modeling approach and can be improved for using in micro modeling.

6. CONCLUSIONS

For enhancement of architectural heritage to future generation, they should be documented properly. Photogrammetric methods or techniques are successfully used to document historic buildings since many years. With the recent developments in the field of computer technology and digital photogrammetry, it is now possible to document architectural heritage in a more accurate and quick way. In the field of architecture, photogrammetry utilizes; photogrammetric method based on photographs and laser scanning. It is possible to form 3D models of structures with the use of photogrammetric data.

For the case study; by using photogrammetric data, 3D model of point clouds and 3D solid model are generated with no bound to any analysis program. At the end of the research, the results below are achieved.

Using photogrammetric techniques for documentation of historic buildings provides more accurate and comparatively fast documentation process. 3D surface model of the building can be formed with the data taken from digital photogrammetry process.

In order to achieve reliable results in documentation of historic buildings, architects and specialists of digital photogrammetry has to work together.

Accurate and reliable 3D analysis models of numerical analysis based on finite element method can be generated through the data of obtained from photogrammetric techniques. However, this process needs to develop through joint work of architects, civil engineers and photogrammetry specialists interested in this field. Once the process of modeling gets faster, the the time consuming process of numerical modeling will be made easily.

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