A METHOD FOR CLASSIFYING THE RISK LEVEL OF THE MONUMENTAL MASONRY STRUCTURES AS A FIRST STEP OF VULNERABILITY ASSESSMENT

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Keywords: Damage assessment, Visual inspection, Monumental masonry structures, Risk classification

ABSTRACT

Monumental historical masonry buildings made of bricks, stones, adobe and mortar are very complex structures. Geometrical typology, construction and organization of the structure, element size and type of construction material vary depending upon the construction period, cultural context to which it belongs and the place where it is located. There are different approaches and methodologies for assessing the damage state of the existing vernacular masonry buildings, concrete buildings and new constructions after any natural hazard. But pre hazard risk assessment of historical structures is not common. It is obvious that there is necessity to develop methods for assessing the damage state of the historical buildings before any hazardous event in hazard prone areas.

The fact that there are many historical structures and few specialists on this field it is very important to develop simpler methods for vulnerability assessment of historical structures and involve non-expert inspectors in those studies. The aim of this paper is to present an ongoing PhD study focused on developing the risk assessment method for monumental historical structures based on visual observations as a first step methodology of the vulnerability assessment. This method will facilitate the specialists’ works on the field of preservation and conservation by using non-expert inspectors as students of architecture and non-expert architects. Since there are some researches on the vernacular masonry buildings shaped of simple geometry, this method is focused on domed and vaulted monumental historical structures which have complex geometry.

INTRODUCTION

Historic structures and monuments are the most important part of the cultural heritage. Many of those structures are masonry that is made of brick, stone, adobe and mortar. The variety of the geometrical typology, construction period, construction and organization of the structure, element size and material types make historical structures very complex (Figure 1). The definition of the historic structure depends on construction period and cultural context to which it belongs and the place where it is located. Due to this reason there is no fixed criterion of the evaluation of historic structures.

During their long life historic structures endured aging, aggressive loads and exposure to aggressive environmental factors that often result in deterioration of many cultural values. Vulnerability assessment and hazard evaluation is essential in hazard prone areas as earthquake is the most important threat against historical structures. There are different approaches and methodologies for assessing the damage state of vernacular masonry buildings, concrete buildings and new constructions after earthquake but evaluation of the potential risk of historic structures before hazard is not common. Since their cultural value and being open to the large assembles of people it is very important to develop pre-hazard risk assessment methods for historical structures. It is obvious that technical codes and guidelines for new constructions are not applicable to the historical heritage buildings.
It is very difficult to make precise quantitative risk assessment for the historical masonry buildings. Study on the structural safety of a historic building necessitates an interdisciplinary team of specialist and requires specific techniques. Safety assessment procedure can be divided into two main steps: the first step is getting the qualitative data through visual inspection of structural damages, decays and deteriorations and second step is getting the quantitative data which requires detailed inspection through laboratory tests, structural analysis etc. Detailed evaluation is a technically complex and expensive procedure. It is very important to use simpler methods that make possible the vulnerability evaluation of the buildings relatively in short time and to limited detailed evaluation to the most critical buildings. The fact that there are many historical structures and few specialists on this field it is very important to develop quick and simplified methods for assessing the safety condition of historic structures as a first step of heritage preservation and get involved non-expert inspectors in the data collection procedure.

This paper presents the ongoing PhD study focused on development a method for assessing the risk level of monumental historical structures based on visual observations. The aim of this method is to classify the risk level of monumental masonry structures as a first step of the vulnerability assessment procedure. This pre-hazard assessment method is based on developing of the “inspection form” for acquiring visual data and developing “the data base system” for evaluating the obtained data and classification of the potential risk of each inspected building as a result of the evaluation. Due to the fact that the researches on this field are mostly on vernacular buildings, this study is focused on domed and vaulted historical monumental masonry structures in Turkey.

The aim of the proposed method is to facilitate specialists’ works on the preservation and conservation field of monumental historical structures and to use non-expert inspectors as students of architecture who are able to make a survey on the existing buildings.
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The methods for assessing the safety condition of buildings can be divided into two main parts: simplified assessment and detailed assessment. Simplified assessment methods are based on qualitative data and require limited additional information and are possible to use in wide range of buildings. Detailed assessment methods are based on quantitative data and require detailed investigation and are possible to use in limited number of structures. To make precise and generally accepted decisions and get quantitative risk assessment is very difficult task. The simplified assessment procedure is formed as the basis for determining the necessity for more complex vulnerability assessment. The final decision of the building requires a team of specialists.

The study on the safety condition of the historic structures mostly is damage assessment after any hazardous event however pre-hazard risk evaluation is not common. Street survey techniques which collect data getting from the exterior of the building are widely used as rapid survey methods after hazards. After any hazardous event observation of the crack pattern and damages on the building is quite enough in order to make the initial decision for the safety condition of the building. If the subject is investigation of potential risk and the pre-hazard safety evaluation of the structures there is necessity of more data. It is very important to investigate the potential vulnerability of the building, by taking into account the geometrical typology of the building, damages, relation with other buildings, load bearing elements etc. Since detailed safety evaluation is a technically complex, time consuming and expensive procedure, it is very important to use simpler methods as a first step vulnerability assessment of different types of buildings and then to limited detailed evaluations to the most critical buildings.

In the field of safety evaluation and hazard assessment there are some researches on the vernacular masonry buildings shaped of simple geometry in the seismic zones. D’Ayala and Speranza developed TOSQA99 method for evaluating the seismic vulnerability of historic buildings which is an integrated procedure for the assessment of seismic vulnerability of historic buildings [1]. After the TOSQA99 the Programme FAMIVE is developed from it [2]. Both methods are based on a failure analysis of the structures through the identification of feasible collapse mechanisms and calculation of their associated failure load factors. Ministry of Home Affairs in India has developed the national vulnerability assessment methodology that consists of three basic procedures. These are Level 1: rapid visual screening, Level 2: simplified vulnerability assessment, Level 3: detailed vulnerability assessment. This method highlights the importance of using simpler procedures that can help to rapidly evaluation of different types of buildings [3]. European countries widely used MDDS - the monument damage diagnostic system which is an expert system based on extensive damage atlas [4, 5].

According to the existing researches it is possible to say that when the subject is safety evaluation and damage assessment of the historic structures there is no current and general method. Depending on the structural typology, culture and economy of the country involved in heritage conservation, methods are different. The common issue is that the first step of the damage assessment is visual screening by using check lists, survey forms, damage atlases etc. It is obvious that definition of the structural elements with complex geometry and taking into consideration the building as a whole during the risk assessment procedure is very important and still is a problem.

The focus of the proposed method is to define all structural elements in their real geometric shape individually, and assess the building as a whole by interrelation of all structural elements and getting the result automatically by the computer. All structural elements are inspected both from
interior and exterior, paying attention of damage state and persistence of damages in both sides. The existence of the damage in both sides of the structural element can be a threat for the building and a clue for any failures. Interrelation between damages of both sides of each structural element and then interrelation of all structural elements by their damages and investigation of the crack scheme and continuity of the cracks for taking into account building as a whole is the main aim of the proposed method.

To be able to inspect each structural element individually and to evaluate building as whole by interrelation between all elements automatically, each element should be represented somehow. Since monumental historical structures are very complex the representation of structural elements and make automatic interrelation between them with their damages is very difficult. The hardest part is to make interrelation between elements with their damages and according to the obtained data to evaluate the condition of the building automatically. The problem is to inspect each wall, pillar, arch and the roof element separately then make automatic relation between their damages and continuity of the cracks. That means to develop a data base system which is able to handle data by using so many parameters and by interrelating those parameters to give information for the whole building. For example if there is a crack on a structural element, interrelating it with the crack on the neighboring structural element to see if there is a continuation of the crack and interrelating the damages on the other parts of the building to see the direction of the building movement. Since each element is inspected separately this automatic result can be got by the elements' codes. To find a general way of representation of the elements which have to be valid for all buildings is very difficult.

Typology of the existing monumental structures is diverse, therefore load carrying system and transitional elements and relation between those elements is different for each structure. To be able to define each structural element in their real geometrical shape as circular, semi circular, curvilinear or irregular and position as orthogonal or non-orthogonal giving axial system to the existing structure is decided (Figure 2). In risk assessment, the geometry and position of the structural element in the building system is very important.

![Figure 2: The example of given axial system of the existing building](image)

The main idea of setting an axial system in plan drawing is to identify existing structural elements. Hence it is not important to draw axis lines precisely like in an application plan drawing and it is not necessary to draw each axis in the center of gravity of the element. The emphasis is to identify all structural elements in simple and understandable way as much as possible by using minimum axis lines to avoid confusions. Vertical, horizontal and diagonal axis lines are drawn along the
structural elements and just vertical and horizontal lines are entitled, in one direction by letters in the other direction by numbers. In case of the wall placed diagonally, the axis line is drawn along the wall in diagonal way and the intersection point of the diagonal wall axis to the other element’s axis is identified with vertical and horizontal axis lines. In case of curved walls, vertical and horizontal axes are drawn at both ends of the curved element and at the point where curvature is tangent to horizontal. Consequently, it is possible to differentiate wall types, pillars and columns according to their codes represented by the intersection points of given vertical and horizontal axes. Examples are given below:

Pillar or column: intersection points of the vertical and horizontal axes; one letter and one number (Figure 2: G6; I6). Linear wall: intersection points of the vertical and horizontal axes at both ends of the wall; two letters and two numbers, two of them the same (Figure 2: A3C3). Diagonal wall: intersection points of the vertical and horizontal axes at both ends of the wall; two letters and two numbers, all different (Figure 2: C2D1). Curvilinear wall: intersection points of the vertical and horizontal axes at both ends and at tangent point of the wall; three letters and three numbers, two of them may be the same or all may be different (Figure 2: G4H3I4).

The proposed method consists of two parts: development of the "inspection form" and development of the "data base system" for evaluating the inspected data and getting automatic result.

**The Development of the "Inspection Form"

The first part of the proposed method is acquisition of the building’s data by using “inspection form” on the field. Development of the inspection form is made by taking advantage of the existing evaluation methods. Processing of the inspection form is widely used method for obtaining data by visual inspections. Although the questionnaire is changed according to material types and construction of the buildings the main parts and the scope is common in many methods. Geometrical data, physical conditions, material types and damages on the buildings are questioned in many forms or check lists mentioned in the previous paragraphs.

The inspection form used in the proposed method is created in the MS Office – Excel software and includes questionnaire composed by six sections. The sections are:

A – General information,
B – Physical information,
C – Photos of the building,
D – Facades,
E – Inspected floor information,
F – The organization of the interior spaces and structural elements.

Figure 3 demonstrates the overall layout of the inspection form. Because of the reason that these pages are not written in English the readability is of less importance in the figure. The data of the geometrical typology, topography, visible damages as cracks, material decays and deteriorations, defects, man-made damages etc and dimensions of the structural elements is collected by using the inspection form. The classification of the risk level will be made as a result of the inspection and this will save the time of specialists working on the field of preservation and conservation when the building necessitates the detailed investigation. Inspection of the structures and data collection by processing the inspection form can be done by non-expert inspectors as students of architecture or non-specialist architects. To avoid the overestimation or underestimation of the damages’ level
by the inspector the inspection form needed to be developed without any judgment left to the investigator.

![Figure 3: The overall layout of the inspection form](image)

Sections A, C, D includes the exterior data and sections E and F includes the interior data of the inspected building. The photos in section B are both from the exterior and the interior of the building. There are also information about the inspector, date of inspection, name of the building, construction date or century, the address, function of the building, earthquake zone and plan drawing with the axial system in the first page (Section A, B). There is also a part for the score and the risk level of the building to be filled after the evaluation. The second page includes photographs of the building. The third page collected data of the facades which includes dimensions, roof system, damages, cracks and interventions. The next pages include the information of the internal spaces of the building as inspected floor, structural elements of each space and their damages and cracks, roof system of each space and transitional elements and interventions.

Each structural element has separate sections according to its axial code. For example facades’ walls will be divided into parts and will be inspected partially entitled by the codes derived from the axial system. Similarly other structural elements as internal walls, pillars, arches, lintels etc. will be inspected separately entitling by their axial codes.
**Processing of the "Inspection Form"**

The user guide of the inspection form is prepared for the inspectors. Before any study or inspections on the field, the inspector will read the instructions and explanations given in the guide. This user guide explains the inspection form, how it should be used, types of damages, and a glossary of used terms.

The inspection process of monumental masonry structures consists of arrangement of site works in the office, inspection on site and processing the collected data to the computer base system in the office. The first step of the inspection is to make a research and study on the building which includes history of the building, earthquake zone and drawings. The earthquake zones map of the Turkey exists on the web site of the Ministry of Public Works and Settlement Government of Republic of Turkey, Disaster Management Division (www.deprem.gov.tr). If there is an architectural drawing of the building, it has to be controlled on the field to see if there are any changes. Afterwards the axial system is set on the building’s plan. After the preparation in the office the inspector can go to the field for the inspection. Depending on the size of the building, an inspection on site might require more than one day. The collected data on the field is paper work and should be transferred on the computer data base system in the office.

Digital archive is very important for having statistical data for the future researches. Monumental structures standing for hundred years were changed during their long life and those changes sometimes affect their structural conditions. Before making any decision on the building for restoration or intervention it is very important to have information of the past of the building.

The capability of the inspection form is tested by the students of the Faculty of Architecture in some buildings in the Historic Peninsula in Istanbul and the inspection form is improved according the discussions and their aspects.

The web base data base system for processing the inspection form in the computer is created in the ASP.NET and Microsoft SQL Server 2008 software and it is under construction (Figure 4). The website is not written in English that is why the readability is of less importance in the figure. This is user friendly system and it makes possible to process the inspection form anywhere there the internet connection is available. Also on the field if there is an internet connection it is possible to input data to the computer.
Figure 4: The login and inspection form pages
Evaluation of the Acquired Data by the Inspection Form

The evaluation of the inspected data is based on the scoring system and will be done automatically by the computer data base system which is under construction. The score of the building will indicate the risk level of the inspected building.

The development of the evaluation form, formulation of data and development of the data base system will be based on the parameters of the Turkish Earthquake Resistant Design Code – 2007, Part 5 and the indexes of the Eurocode 6 and Eurocode 8 [6,7]. Beside these criteria, structural factors as geometry of the building, load bearing elements, supporting system of the structure, damages on the structural elements, earthquake zone and relation between damages will be considered in the final score. Especially the crack pattern and direction and the continuity of the cracks are very important for the evaluation of the safety condition of the building. Due to the fact that the evaluation will be done automatically by the computer data base system the codes of the structural elements will give possibility to make relation between all individually inspected elements.

The designated evaluation parameters are:
Area of the wall to area to building ratio (in X and Y directions),
Effective shear ratio,
Slenderness of the walls,
Area to weight ratio.

In monumental masonry structures the geometry and the organization of the structural elements is very complicated and load bearing schemes are different in each structure. In evaluating the structural condition of the monumental buildings, Part 7 of the Turkish Earthquake Resistant Design Code – 2007, which divides the level of the knowledge of the acquired data from buildings into three parts, will be used. These three parts are: limited knowledge, intermediate knowledge and detailed knowledge. The coefficients that will be used in the evaluation procedures are 0.75 for limited level, 0.90 for intermediate level and 1.00 for detailed level. According this classification the limited knowledge includes geometrical typology, structural system’s elements and organization of the structure and the construction materials, intermediate knowledge includes connections and stability of the structural elements and the building, and detailed knowledge includes detailed on-site and laboratory investigations [6].

Due to the fact that the data obtained by processing the inspection form is based on visual inspections and includes detailed information of the geometry, structural organization, load transforming scheme, the damage state of the structural element and its continuity all through the building, the evaluated data can be considered as intermediate knowledge with 0.90 level of knowledge coefficient.

CONCLUSIONS

Since there are many historic structures and few specialists on this field it is very important to make researches on the potential risk of the historical heritage buildings in the seismic prone areas as a first step of vulnerability assessment and facilitate the works of specialists. Risk assessment is the fundamental institutional process and requires team work.

In preservation of the cultural heritage, pre-hazard risk assessment of historical structures will help to identify the potential seismic hazard in existing historical buildings for hazard mitigation, disaster preparedness and prior knowledge of potential hazards. Depending on the aim, budget and requirements there are simpler and detailed methods for assessing the present condition and
the potential risk of historic structures. Detailed analyses are technically complex, expensive and take more time and can be applied to limited number of buildings. It is very important to develop and improve the first step evaluation methods and to involve non-experts as architecture students and non-specialist architects in the risk assessment of the historical heritage buildings. By this way the detailed evaluation procedures could be applied and limited to the most critical buildings.

The proposed method in this study is pre-hazard risk assessment of monumental historical structures based on visual inspections which give the initial information for the evaluation of the safety condition of the building. The main idea of this method is to inspect many buildings in relatively short time, to make evaluation for getting the score of the risk level of the inspected building automatically by the computer data base system, to classify the inspected buildings according to their risk level and orient the buildings under high risk to the specialists for detailed investigation and to facilitate the experts’ works on the field.

ACKNOWLEDGEMENTS

Authors would like to thank to Yildiz Technical University Scientific Research Projects Foundation for supporting the study and to Ass. Prof. Elif Karsligil, Recep Yaşar and Yigit Ulguc from Yildiz Technical University, Computer Science Department for creating the data base system.

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