Construction and Building Materials 113 (2016) 752–763

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Seismic retrofitting of the historical masonry structures using numerical approach

Cemil Akcay [a], Tarik Serhat Bozkurt [b], Baris Sayin [a,*], Baris Yildizlar [a]

[a] Istanbul University, Department of Civil Engineering, Turkey
[b] Istanbul Technical University, Department of Architecture, Turkey

HIGHLIGHTS

- The laboratory tests and in situ analyses of samples taken from the building have been performed.
- The numerical analysis of the prepared building model using finite element software have been given.
- The restoration applications using laboratory, in situ and numerical analysis results have been presented.

ARTICLE INFO

Article history:
Received 23 December 2015
Received in revised form 9 March 2016
Accepted 21 March 2016
Available online 25 March 2016

Keywords:
Historical structures
Restoration
Retrofitting
Numerical analysis
Lab test

ABSTRACT

In historical buildings, because of the deterioration on structural members including slab and walls that complete their life cycle in time, due to environmental conditions; restoration applications have become necessary to increase the material durability level and to have adequate level of structural strength in order to resist dynamic effects such as earthquakes. This paper focuses on assessment of historical masonry structures from the point of seismic resistance. The entire process is illustrated using case study from a historical masonry structure. In this study conducted in this respect, a historical building is restored within the scope of laboratory studies and numerical analyses. The first stage of the study includes plaster analyses and mechanical tests conducted on the samples taken from the said building. In the second stage, i.e. numerical analysis, the building's existing 3D computer model was prepared and materials, members that are inadequate in terms of strength were determined. The third stage includes restoration applications by using laboratory and numerical analysis results. Within the scope of restoration applications, structural cracks on the walls were repaired using the injection method; volta slab (brick floor arches), exterior facade walls, interior walls and door/window gaps using different techniques were strengthened. In this study, it was aimed to increase material durability and structural strength by using conventional and modern techniques within the scope of laboratory tests and numerical approaches in recovering the historical buildings.

1. Introduction

The conservation, preserving and restoration of historical masonry structures belonging to the cultural heritage, strengthening their main structural members, are becoming a very important issue in Turkey. Therefore, the structures need restoration to survive their life as a result of aging and increasing load demand. Many historical structures have been restored in order to resist these effects [1]. Masonry constructions are typically complex structures and there is lack of knowledge and information concerning the behavior of their structural systems, particularly in what regards their seismic response. Typically, these structures are more massive than today's structures and usually carry their actions primarily in compression [2]. According to results of the work developed within the ICOMOS 2001 recommendations, a thorough understanding of the structural behavior and material characteristics is essential for any project related to the architectural heritage. It is recommended that the work of analysis and evaluation should be done with the cooperation of specialists from different disciplines, such as earthquake specialists, architects, engineers and art historians. In addition, it is considered necessary for these specialists to have common knowledge on the subject of conserving and upgrading or strengthening the historical buildings [3].

The historical building in which restoration was carried out is located in Istanbul University land in Fatih district, Süleymaniye

* Corresponding author.
E-mail address: barsayin@istanbul.edu.tr (B. Sayin).

http://dx.doi.org/10.1016/j.conbuildmat.2016.03.121
0950-0618/

parish, 579 building block, 1 plot and in the historical peninsula of Istanbul which is listed in the World Heritage List of UNESCO. This historical building is registered by Istanbul IV Cultural and Natural Heritage Preservation Board as a cultural heritage to be preserved with the preservation group I [4,5]. The historical building is named as Beyazit secondary school in German blue map dated 1911–1913 while it is named as Court of First Instance in Pervititch map dated 1935, indicating changes in the function of the building [6,7]. It is stipulated that the latest function of the building, before it was handed over to the University, is student dorm within the Ministry of National Defence, a period in which it saw the most significant changes.

Preparing the restoration project, historical photos and old maps were utilized in collecting data and documents on the building facade; therefore, information on structure form, roof form, storey height of the building, roof patio, storey count, relationship with the neighbouring buildings and location of the windows was obtained [6–8]. Views of the historical building before the restoration are presented in Fig. 1.

In order to improve the unfavourable condition of the said building in terms of safety, function and aesthetics and bring it in compliance with its historical identity, relief and restitution project based on old-dated maps and photos were prepared and a restoration project was drafted based on this data. The restoration project was found suitable and approved by the decree of Istanbul No. I Regional Board of Preserving Cultural Heritage [9].

A number of researches have been carried out to investigate the seismic resistant of historical masonry structures [2,10–28]. Asteris et al. present a methodology for earthquake resistant design or assessment of masonry structural systems [2]. Valluzzi et al. investigated that the structural rehabilitation of monumental area. In the paper, after a general presentation of the main properties and of the most relevant deterioration phenomena of the principal parts of the monumental area, the methodology that is being used for the structural diagnosis, for the implementation of guidelines for the future interventions and for the maintenance of the restored conditions are presented [15]. Aktas and Turer focused on seismic evaluation and strengthening of Nemrut monuments. The simulations showed vulnerability of cut-stone blocks separating from one another under seismic action, and simple strengthening solutions were proposed [20]. Mele et al. analysed a basilica-type church in order to assess its structural behavior and seismic vulnerability. For this purpose, an effective two-step procedure has been used, consisting of 3D static and dynamic linear analyses of the structural complex, and 2D nonlinear push-over analysis of the single macro-elements [24]. Bernardeschi et al. described the numerical techniques implemented in the finite-element code NOSA for structural analysis of masonry constructions [27]. Abruzzese et al. evaluated the risk of collapse of the Huzhu Pagoda, one of the oldest masonry pagodas built in the XI century. In the study, mechanical properties of the masonry material have been obtained by experimental tests on small specimen and the mechanical behavior of the structure has been evaluated via numerical models. The static analysis of this ancient pagoda constitute a prerequisite base for the evaluation of its structural behavior leading to a suitable maintenance program [10]. Barbieri et al. performed a structural analysis of a historic masonry building subject to significant static instabilities due to an overturning of the longitudinal facades related to ground settlements [19]. Mahini proposed a macro-modelling approach and the performance of a CFRP-retrofitted in historical building. The brick and adobe, prism samples of the building have been modelled by commercial code, which uses smeared-crack materials and eight-noded isoparametric, solid elements [14].

In this paper, restorations applications in a historical building within the scope of lab tests and numerical analyses were presented within the scope of laboratory tests, numerical analyses and a cross-disciplinary study of civil engineering and architecture. Conventional and modern techniques were based on intervention decisions as a result of both laboratory studies and numerical analyses on the building. This paper is aimed to become an exemplary study in retrofitting applications in historical buildings, especially in terms of increasing the seismic resistant.

Fig. 1. Facade views of the structure the pre-restoration (a–f).