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Vulnerability Assessment of Two Instrumented Masonry Buildings in Antakya (Hatay, Turkey)

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Abstract

Masonry structures constitute one of the predominant building types with the highest level of seismic vulnerability. The comparison of recently generated fragility curves for masonry structures shows a remarkable variety of the classification criteria and a large scatter of the vulnerability states for comparable subclasses. It should also be noted that it is not possible to simulate seismic behavior of all available masonry construction types by using simplified approaches and gross assumptions. As it will be discussed, no unique typology is available which could be applied to the building stock in the considered study region, namely the city of Antakya, directly. Therefore, a multi-level approach is introduced by combining elements and information from empirical, analytical and experimental vulnerability assessment procedures. For this procedure, two unreinforced masonry buildings have been instrumented with permanent building monitoring systems. The recorded events are used to determine the dynamic behavior parameters of the buildings to calibrate their analytical models. Nonlinear performance analyses have been carried out for the calibrated models in order to assess their damage levels and obtain more reliable vulnerability functions. The final issue of these investigations is to provide reliable data for damage scenarios in the frame of a Master Plan for the city of Antakya.

Keywords: *masonry structures, earthquake engineering, structural dynamics, experimental and analytical vulnerability assessment, nonlinear analysis.*

1 Introduction

The last decade in earthquake engineering research has been dominated by engineered multi story reinforced concrete (RC) structures, because of relatively more prevalent heavy damage during strong earthquakes and the high number of causalities, accordingly. Generally, damage in masonry structures has escaped to serve as focus of interest. Nevertheless, masonry structures are the dominant building type in many regions until today. Further insight into the vulnerability of masonry structures is of general interest, in particular in low seismicity areas and old city centers.

This is also true for the city of Antakya, founded in 300 BC, which has been an important confluence of states, faiths and peoples from its earliest times. Therefore, various aspects affect the masonry building stock especially in the old part of the city, which leads to the need for new evaluation methods as well as procedures to describe the behavior under earthquake loads in a reliable manner. In the framework of the *Seismic Risk Assessment and*

Mitigation in the Antakya Maras – Region (SERAMAR) and *TUBITAK-BMBF Intensified Cooperation (IntenC) project (107M445)*, experimental and analytical vulnerability assessment of RC structures have been carried out (Genes *et al*., 2008; Genes *et al*., 2009a; Genes *et al*., 2009b; Genes *et al*., 2011). On the basis of this, a building typology for RC structures has been developed (Schwarz *et al*., 2009). Representative buildings of each type have been investigated experimentally and analytically by permanent instrumentation for strong motion records (Abrahamczyk *et al*., 2008), with temporary instrumentation for forced vibration or ambient vibration records (Genes *et al*., 2011).

Similar investigations have been conducted for masonry buildings under the use of the existing local building stock data of the study area from the building stock survey including the already assigned vulnerability classes according to EMS-98 (Grünthal *et al.,* 1998) and the developed building typology for the RC structures, which will be used as model for the masonry structures as well.

Due to the inherent characteristics of the building stock in the Antakya city, the current and common evaluation methodologies are not sufficient to describe the vulnerability of the masonry building stock realistically. Therefore, a new procedure is proposed in the TUBITAK-BMBF IntenC project (110M748) and preliminary results and details of the procedure are discussed in the study of Abrahamczyk *et al*. (2012), which gathers past experiences, empirical as well as analytical methods together with different experimental testing. In that study, using a specific scheme of ranking criteria, representative buildings are identified. Depending on the availability of the basic information describing the structural layout, buildings are selected for a multi-tasking in-situ instrumental testing procedure, which in each phase is related to the outcome of parallel analytical investigations by using different analysis methods and programs. Temporarily installed weak-motion sensitive velocity-seismometers as well as permanent strong-motion building instrumentations are used to measure the synchronous spatial building reaction at different elevations. On the basis of the instrumental data, the dynamic characteristics are investigated and compared with the numerical results. Instrumental and numerical data are used to calibrate the finite element model of the considered buildings.

Considering the aforementioned procedure, two masonry buildings have been instrumented with permanent building monitoring systems. The recorded events are used to determine the dynamic behavior parameters of the buildings to calibrate their analytical models. Nonlinear performance analyses have been carried out by using the calibrated models to assess their damage levels and determine more reliable vulnerability functions. The main goal of these investigations is to provide reliable data for damage scenarios in the frame of a Master Plan for the city of Antakya.

2 Realization of the Study

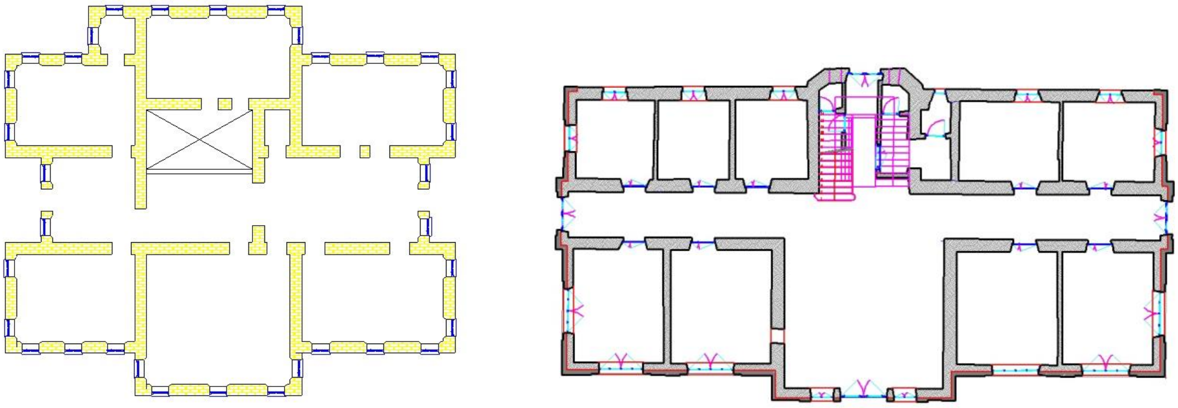
2.1 Analytical Vulnerability Assessment

For the analytical vulnerability assessment of the instrumented buildings, current methodologies and programs for the assessment of the building response are going to be applied. The capacity curves will be calculated by the use of the static nonlinear push over analysis. Since, the instrumented buildings are the representatives of the predominant and categorized building types, most of the analysis will be considered in more detail on these case study buildings. In addition to these analyses, from local inspections and archive data search, the arrangement of structural walls within the ground plans, the openings, the floor type as well as other vulnerability affecting measures will provide the basis for the creation of spatial (3D) models, which will be analyzed by different software tools.

2.2 Selections of Buildings for Instrumentation

The building selection process for permanent instrumentation is the most important issue for in-situ testing. Because, the obtained data should be useful to get the dynamic characteristics of the building, and the analytical model of the instrumented building could be obtained with minimum assumptions for unknown parameters.

In addition to the number of stories, seismic behavior of masonry buildings is affected by regularity and symmetry in plan, the load bearing wall material as well as criteria on wall length and openings in walls as indicated during the comparison of the available fragility functions by Abrahamczyk *et al*. (2012). A building rectangular in plan (i.e. shaped like a box) is inherently stronger than a building with wings (i.e. L-shaped or U-shaped). An irregularly shaped building will twist as it shakes, which increases damage. The lateral resistance during earthquakes is provided by the load-bearing walls and is mainly affected by the placement of openings in walls as well as the construction material itself.



a) Plan of the Ata Collage (1^{st} Building) **b)** Plan of the Municipality (2^{nd} building)

Figure 1. Plans of the selected buildings for instrumentation

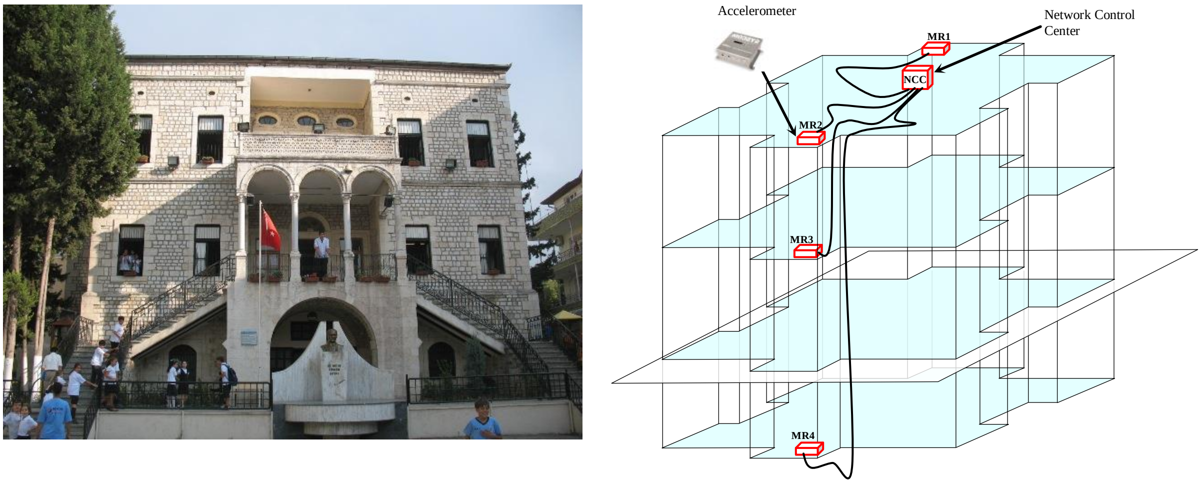
By considering the affects summarized in the former paragraph, the selected buildings for instrumentation are almost symmetric in plan and has regular openings in their walls. The structural plans of the selected buildings are given in Figure 1. The first building is a school building and instrumented in October 2011. The second building is used as the cultural center of the city and also as the exhibition center. This building is instrumented in May 2012.

2.3 Experimental Investigations

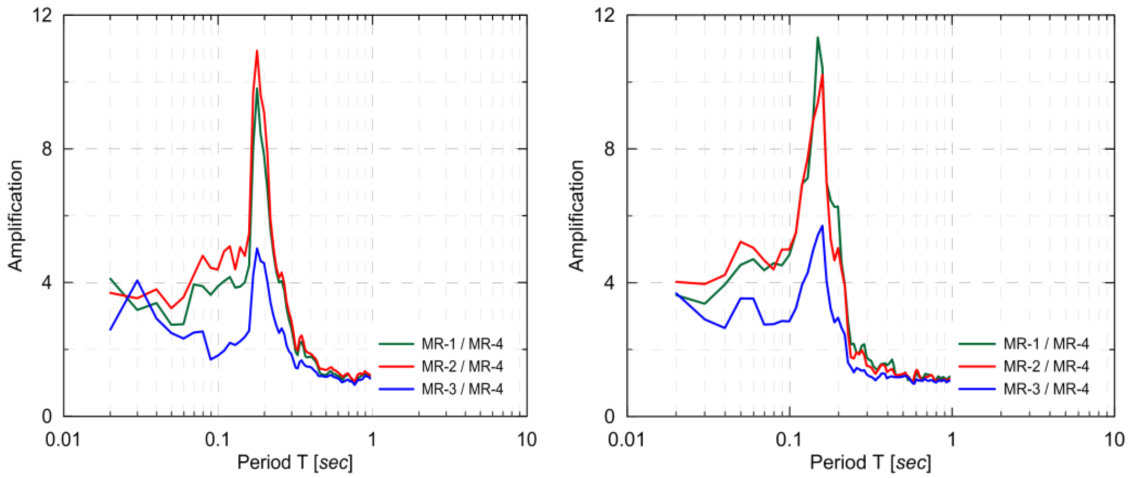
In the framework of the IntenC project (110M748), different kinds of tests are foreseen to provide data for the analytical investigation to improve the quality of the structural models as well as the final damage prognosis. At the current state of the project, two masonry buildings have been instrumented. The first masonry building (Figure 2a) was instrumented by four tri-axial strong-motion recorders. Figure 2b indicates the applied instrumentation scheme, which follows the schemes from previous instrumentation of RC buildings in Antakya (Abrahamczyk *et al.,* 2008). Due to limited space around the building and the use as a school, a free-field station could not be installed. Instead, one sensor was installed on the 2^{nd} floor in the same line of the sensors on the ground floor and roof.

On April 4, 2012, a magnitude M_L=4.2 earthquake occurred in the vicinity of Antakya and produced amplification in the building, which exceeded the adjusted trigger-levels. It's the first measurement of the response due to an earthquake at that building after its instrumentation in October 2011. However, several other earthquakes occurred within a 200 km radius around Antakya. Most of them could not be measured by all of the sensors because of the settings of the trigger-level (KOERI, 2012). The recorded ground motion and building response accelerations were analyzed by calculating the response spectra as well as the spectral relations between the top and the basement in each direction separately. Figures 2c and 2d show the spectral relations (amplification) between the two roof sensors to the basement as well as the mid-floor sensor to the basement in x- and y-directions. The distinctive peaks indicate the fundamental periods, *T,* in each direction of the building. By the measurement of future earthquakes with different magnitude, it may be possible to validate these first results.

The second masonry building (Figure 3a) was instrumented by four tri-axial strong-motion recorders. Figure 3b indicates the applied instrumentation scheme, which also follows the schemes from previous instrumentation of RC buildings in Antakya (a school building and a residential apartment) (Abrahamczyk *et al.,* 2008). Just like the first building, because of the limited space around the building and the use of as an exhibition hall, and also due to crowded traffic load around the building, free-field station could not be installed. Instead, one sensor was installed on the 2^{nd} floor in the same vertical line of the sensors on the ground floor and roof. Due to adverse weather conditions and the delay in getting permission for instrumentation, the building could be instrumented during the second half of May 2012. Unfortunately, no event could be recorded and analyzed to find out the vibration period, mode shape and amplification due to ground shaking experimentally prior to the submission of this paper.

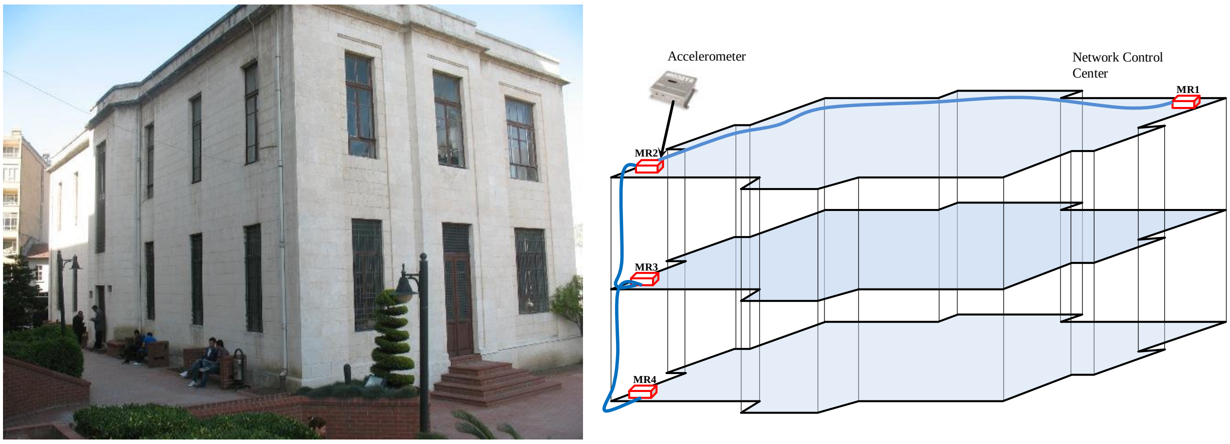


a) View of the instrumented school building b) Applied instrumentation scheme



c) Analyzed EQ record (amplification) in x- axis d) Analyzed EQ record (amplification) in y- axis

Figure 2. Applied building monitoring system to the 1st building and response of the building to first EQ record



a) View of the instrumented municipality building **b)** Applied instrumentation scheme

Figure 3. Applied building monitoring system to the 2nd building

2.4 Analytical Studies

The next step is to construct analytical models of the instrumented case study buildings. For this purpose, MAS, an earthquake analysis program for masonry buildings, has been used (Mengi *et al.* 1992). The analysis program MAS employs a nonlinear model for masonry wall panels assuming that they have resistance in their own planes and have negligible rigidities in out-of-plane direction. In modeling of masonry walls, the spandrel parts above and below openings are neglected.

Eigenvalue analyses are conducted for both buildings to compare the predictions of the linear dynamic models for the free vibration periods of the structures with that obtained experimentally. The required input parameters to conduct this analysis in MAS software are the floor masses, mass moments of inertias, elastic shear modulus (G) and viscous damping coefficient (G´). In the analysis program MAS, viscous damping mechanism is employed to account for energy dissipation. Masonry can not dissipate much energy through material hysteresis under cyclic loading and the governing energy dissipation mechanism is the internal friction, which increases with shear strain and cracking. Floor masses and mass moments of inertia are calculated by considering the contribution of masonry walls and floor slabs to the dynamic motion. The elastic shear modulus is obtained from the compressive strength of masonry (f_m) with the following expression (FEMA, 2000)

$$G = 220 f_m \tag{1}$$

Both buildings had been constructed with stone masonry units. The value of compressive strength used in the analysis is taken from a previous extensive study regarding the seismic performance of unreinforced masonry buildings in Turkey (Erberik 2008). However it should be noted that the material properties can differ due to local practices. Hence the analysis will be repeated and the results will be revised after conducting experimental tests on local masonry units

It is possible to obtain the viscous damping coefficient G´ as a function of the shear modulus G by using the formulation below (Mengi *et al.* 1992)

$$G' = G\left(\frac{\xi_1 T_1}{\pi}\right) \tag{2}$$

In view of experimental results and previous studies (Mengi *et al.* 1992, Tanrıkulu *et al.* 1992, Sucuoğlu and Erberik 1997), the damping coefficient is considered as constant in the linear elastic range and its value for the first mode is assumed as 0.10. The empirical formulation that is used to estimate the fundamental period of masonry buildings is

$$T = 0.06\, n \tag{3}$$

where n is the number of stories. Calculated values of elastic shear modulus and its viscous damping counterpart are used as input parameters in eigenvalue analysis.

The results are presented in Table 1. For both buildings, the first three vibration periods, corresponding damping ratios and mode shapes are listed. For the mode shapes DX and DY denote translation in X and Y directions respectively whereas RX denote the torsional mode. In the experimental stage of the study, the fundamental periods of the buildings had been obtained as xx s and xx s, respectively. Therefore it can be stated that analytically obtained values of the vibration period agree quite well with the experimental values.

Table 1. Dynamic properties of the case study buildings.

Dynamic properties	**First Building**			**Second Building**		
Period (s)	0.19	0.14	0.12	0.15	0.11	0.10
Damping ratio (%)	10.49	13.92	16.22	13.5	18.43	20.64
Mode shape	DY, RZ	DY	DX	DX	DY	DX

2.5 Experience-based Vulnerability Assessment

As discussed in Section 2.2, seismic behavior of masonry buildings is affected by number of stories, regularity and symmetry in plan, the load bearing wall material, length of the walls and the openings in the walls. It is a known fact that the lateral resistance of masonry structures during ground shaking is provided by the load bearing walls and is significantly affected by the placement of the openings and the material used for construction. Therefore in this study, different investigation levels will be carried out to evaluate the seismic performance of the instrumented representative masonry buildings on the basis of the experiences from past earthquakes (see Figure 4). By using the gathered data from the archive of the Antakya municipality, a multi-level procedure is going to be carried out for the masonry building stock. This study is still in progress and the obtained results will not be presented in this paper.

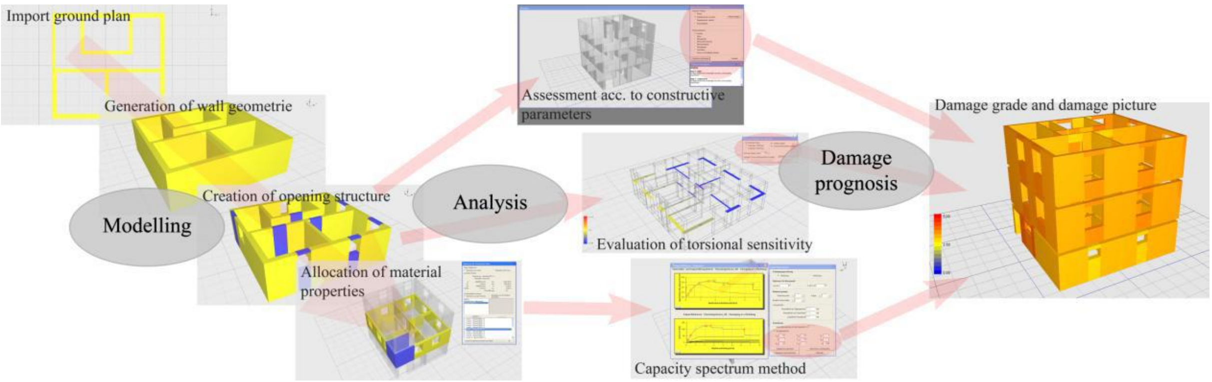


Figure 4. Evaluation and investigation levels for the damage prognosis of masonry buildings (Abrahamczyk *et al.*, 2012)

In Level 1, the constructive parameters are going to be investigated on the basis of wall thickness, wall dimensions and opening structures with the purpose to evaluate these parameters and the effects on the seismic performance. Additionally, the wall shear ratio of each building is going to be determined and compared with the requirements according to Turkish Seismic Code (2007) and also Eurocode 8 (CEN, 2003).

In Level 2, the impact of irregular ground plan, e.g. the increase of the demand in the individual structural walls due to effect of bi-directional eccentricities between mass and stiffness centers as well as the dynamic amplification due the coupling of translational and torsional modes, will be investigated.

For the assessment of the seismic performance; Levels 1 and 2 shall also ensure decision criteria for the transfer of the analytical and experimental findings from individual representative buildings to all masonry building types in the stock. In Level 3, the capacity curves will be calculated by the use of the static nonlinear push over analyses. All the elaborated ground plans will be analyzed by standard softwares like 3Muri, MAS as well as BLM software.

In order to link the empirical and analytical approaches, it is indispensable to validate all the results on the experiences after damaging earthquakes. Therefore, it is foreseen to use available damage statistics from Turkey and Germany to provide a data basis for the cross correlation of the applied and developed methods.

3 Conclusions

The building stock of the mid-size city of Antakya has been elaborated within the SERAMAR project leading also to a first level database for a more refined consideration of the masonry buildings. As it can be concluded from a series of comparative studies, models and vulnerability related functions of similar studies cannot be adopted directly to this city. Because of their high vulnerability and the inherent heterogeneity due to the historical process of modifications and period-depending use of locally available materials, it has been decided to develop a new building typology, which should be supported by a complex evaluation and detailed investigation procedure such as permanent instrumentation.

In the frame of the IntenC project (110M748), a masonry school and municipality buildings could be instrumented by a strong-motion building monitoring systems and results from the first EQ-record are presented for the school building. The main focus of the next step will be to establish a reliable link between the analytical and empirical as well as experienced based approaches. Therefore, further ground plans will be analyzed and calculated with common programs. After the successful installation of the building monitoring systems and the recording of the response during an earthquake, the data will be used to calibrate and validate the analytical models.

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