BUILDING MONITORING FOR SEISMIC RISK ASSESSMENT (I): INSTRUMENTATION OF RC FRAME STRUCTURES AS A PART OF THE *SERAMAR* PROJECT

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ABSTRACT :

The main objective of the ***SERAMAR*** project (***Se****ismic* ***R****isk* ***A****ssessment and* ***M****itigation in the* ***A****ntakya-Maraş* ***R****egion)* is to utilize current tools for earthquake risk assessment and to establish a unique partnership between universities, professional associations as well as local governments that might serve as a model for similar future activities in Turkey and adjacent areas. In order to reach this goal a thorough microzonation including vulnerability and social preparedness studies ***in forefront of*** a damaging seismic event have to be conducted.
In the first phase of the project, the entire building stock was surveyed and classified on the basis of the European Macroseismic Scale EMS-98. Following the principles of this empirical approach, the most likely and probable ranges of vulnerability classes have to be identified. In addition, predominant building types and their structural layout are elaborated in advance of nonlinear time-history and pushover analyses.
In this context, the instrumental investigation of buildings being representative for the study area becomes an essential part of the project to calibrate the models and to predict reliable capacity curves as well as scenario-dependent damage pattern or failure modes. The latter should be suited to derive mitigation strategies.
Based on different decision criteria, three multistory RC frame structures have been chosen and equipped with modern Seismic *Building Monitoring Systems* (BMS) each of which consists of four triaxial strong-motion accelerometers of type MR2002+. After a 2 year test period, first results from the permanent instrumentation are available and provide a preliminary basis to reinterpret the structural response under seismic action.

KEYWORDS: Instrumentation, RC structures, seismic risk, building monitoring

1. THE SERAMAR PROJECT

In close collaboration with local partners, Earthquake Damage Analysis Center (EDAC) of Bauhaus-Universität Weimar initiated a Turkish-German joint research project on ***Se****ismic* ***R****isk* ***A****ssessment and* ***M****itigation in the* ***A****ntakya-Maraş-****R****egion* (***SERAMAR***) [*EDAC, 2004*].
Most of cooperation projects on microzonation in Turkey are more or less concentrated on the Marmara region around the megacity Istanbul because of an inflated expectation of a major earthquake there during the next 25 years. The seismic hazard in the Sea of Marmara region in Turkey is indeed high, but by no means uniquely so. For this reason, there is the urgent need to center on alternative high-seismicity regions of Turkey.
The ancient city of Antakya lies in the southernmost tip of Turkey, and is currently built on an alluvial plain through which the river Asi flows. As with many other urban settlements in Turkey it has experienced a rapid expansion during the last several decades, with many vulnerable buildings added to its stock. With regard to the ancient history of the city Antakya and its large number of historical buildings the proposed project on seismic risk assessment and mitigation may also serve for the protection and preventive conservation of Cultural Heritage.

Judging by historical precedence, major earthquakes on this branch of the Dead Sea-East Anatolian fault system have a real potential for occurrence in the city.
To the main aspects belong the survey and evaluation of the vulnerability of the existing building stock and the allocation of reliable basic data, in order to establish ascertained measures and to generalize them on the basis of sociological acceptance analyses. Furthermore an international new approach to instrument buildings will be proven. It implies the real building behavior and the calibration of the analytical models [*EDAC, 2006*]

2. CLASSIFICATION OF BUILDING STOCK

2.1. Building types and typical parameters

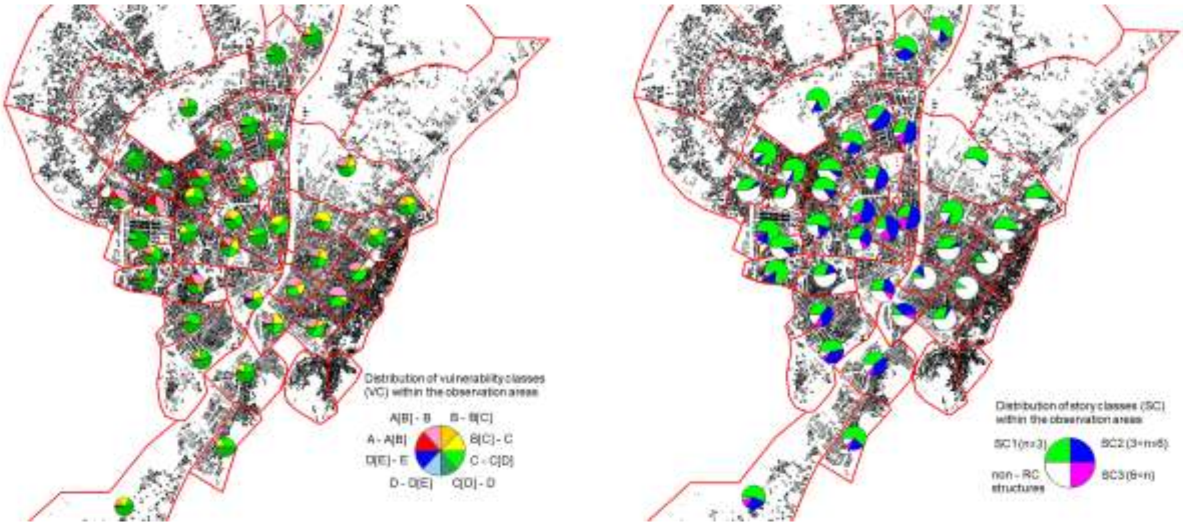
In preparation for the building survey the cadastral map of Antakya was processed. After a first rapid screening of the urban areas and a photo documentation of representative buildings, a preliminary classification of the construction types was assembled. On this basis and according to the EMS-98 [*Grünthal et al., 1998*] a data entry form was developed for the dominant building types as well as a scheme to incorporate design defects. Figure 1 shows a part (RC frame buildings) of the developed cheat sheet to train the staff foreseen for the building survey. Criteria for the allocation of the offered vulnerability classes are given. Transition classes (e.g. B-C) are explicitly allowed. In addition to the common census of the building types further criteria are investigated in order to conduct a more detatiled vulnerability assessment with regard to the postprocessing. This concerns e.g., criteria of layout irregularity as well as structural peculiarities which could yield to special damage pattern. Based on the historical center of the city the whole area was investigated except for the outskirts (see Figure 2 – all areas highlighted with data).

2.2. Assignment of vulnerability classes

During the building stock survey those influencing factors are considered, which can be connected to different failure mechanisms such as short column, soft story or cantilevering upper story. In addition also those objects are monitored, which were constructed without any control during the execution of the construction work (wildly/ rampant built). On the basis of all these data, which were edited in several layers of a GIS format, vulnerability classes for each building were determined. Figure 2a shows the distribution of the vulnerability classes within the observation areas. With these results the requirements for intensity-based scenarios are created.

<table>
<tr><th colspan="2">Examples</th><th colspan="6">Ranges of vulnerability classes</th><th rowspan="3">Assign-ment</th></tr>
<tr><td rowspan="4"></td><td rowspan="4"></td><th>A</th><th>B</th><th>C</th><th>D</th><th>E</th><th>F</th></tr>
<tr><td colspan="6"></td></tr>
<tr><td colspan="6">very seriously pre-damaged (before-collapse state)</td><td>A</td></tr>
<tr><td colspan="6">pre-damaged/weathered state and irregular plan or elevation shape (e.g. soft story)</td><td>B</td></tr>
<tr><td rowspan="4"></td><td rowspan="4"></td><td colspan="6">pre-damaged/weathered state or irregular plan or elevation shape (e.g. soft story)</td><td>B-C</td></tr>
<tr><td colspan="6">without earthquake-resistant design (ERD)</td><td>C</td></tr>
<tr><td colspan="6">with moderate level of ERD</td><td>C-D</td></tr>
<tr><td colspan="6">with high level of ERD</td><td>D</td></tr>
<tr><td colspan="9">........ probable range; —— less probable, exceptional cases; ○ most likely</td></tr>
</table>

Figure 1 Part of the cheat sheet (RC buildings without ERD) designed for of the building stock survey



a) Vulnerability Classes acc. to EMS-98 b) R.C. type buildings classified into Story Classes (SC)

Figure 2 Results of the building stock survey at the level of observation areas

3. REINFORCED CONCRETE FRAME STRUCTURES

3.1. Building types

The definition of building types requires the abstraction and reduction of the building characteristics (which is often hidden by the externally appearance) to the failure and damage-determining criteria of the structural system under seismic impact. This means, the defined building types have to preliminary differentiate the different vulnerability classes of the existing buildings and to anticipate comparable damage pattern under comparable seismic impact.

The characterization for analytical investigations requires that single objects preferably represent a large number of buildings. The advantage of the investigation area Antakya consists in the fact that a major portion of the building stock can be traced back on reinforced concrete frame type structures which can be analytically investigated to predict reliable building damage. Around 70 % of Antakya's building stock consists of reinforced -concrete structures, which led to the decision to subclassify these structures into different story classes (SCi n). Figure 2b shows the distribution of storey classes for R.C. structures within the different study areas. Three different story classes are defined: SC1 ($n \leq 3$), SC2 ($3 < n \leq 6$) and SC3 ($n > 6$). With regard to Figure 2b it becomes obvious that other building typologies than R.C. structures are prevalent in the historical inner parts of the city (the 'Old Town' and adjacent areas along the eastern hill side).

3.2. Building typology

It is intended to further classify the R.C. frame structures according to the following code-like order: RC-Use-VCP-VCS-NoSt with RC = reinforced concrete; Use = P/B (private/ business) and NoSt = number of stories. Within the recently drafted typology, a more refined description of building types with respect to the primary and secondary vulnerability-affecting characteristics class (VCP, VCS) has been applied. VCP stands for the ground or primary type (BT) without major damage-enforcing particularities. Secondary aspects (VCS) are related to design or construction defects (and their combined occurrence) like soft story (ss), cantilevering beams/floor slabs combined with soft story (cus), widely ramped building (wrb) etc. Special attention is paid to the 'pseudo-regularity (psr)' as a synonym for the quite irregular arrangement of structural elements leading to relative uncertain transmission and flow of the seismically induced forces. For the predominant types RC-P-BT-2 and RC-P-BT-2 about 2000 and 900 buildings respectively could be documented as an outcome of comprehensive field surveys. About 25 sub-groups are distinguished with more than 50 individual representatives. The analytical and instrumental investigation of representative buildings of these types will be realized in a further ongoing project [*Schwarz et al., 2009*]).

4. INSTRUMENTATION OF REPRESENTATIVE RC FRAME STRUCTURES

4.1. Overview

As an outcome of the ***SERAMAR*** project it was decided to instrument three buildings within the urban area of Antakya with *Building Monitoring Systems* provided by SYSCOM Instruments SA. Therefore a variety of eligible buildings had to be pre-selected and checked whether they are suited for the instrumentation or not [*EDAC, 2006*].
Since most of the casualties of the Turkish earthquakes in recent years were caused by the collapse and serious damage of multistory reinforced concrete frame structures with hollow brick masonry walls. The investigations are concentrated on this highly vulnerable building type. In order to thoroughly select suitable buildings for instrumentation, a priority list for a number of potential test objects was elaborated [*Schwarz et al., 2006*]. Especially properties like vulnerability, representativeness and specific user requirement (importance) are considered.
Figure 3 shows the three instrumented buildings as well as their recently prepared structural models (using the program system ETABS Nonlinear vs. 9.0.9). Additionally, the sensor channels of the installed instruments are illustrated in order to show the position of the sensors. Note: The channels of the free-field stations are not depicted.

The reference to the current building stock can described as follows (see [*Schwarz et al. 2007*]):

- The 3(4) story reinforced concrete frame type school building (BMS-1) represents a widely spread typical project for school buildings in Turkey.
- The 6 story reinforced concrete hospital (BMS-2) stands for a partly retrofitted (by shear walls) reinforced concrete frame type structure.
- The 5 story reinforced concrete frame type residential building (BMS-3) is considered to be characteristic for the city center of Antakya (SC2: $3 < n \leq 6$), see also Figure 2b.

Another residential building (BMS-4) could be instrumented in 2007 which is also of reinforced concrete frame type (story class SC2) but being located on different subsoil condition than BMS-3.

(a) BMS-1: Hüseyin Özbuğday Lisesi (school) | (b) BMS-2: Hatay Devlet Hatanesi (hospital) | (c) BMS-3: Akdeniz Apartman (residential building)

Figure 3 Instrumented buildings, location (direction) of the sensors (channels) and their structural models

a) Sensor on the top of the structure b) Central acquisition unit c) Free-field station

Figure 4 Technical realization and mounting of the equipment

4.2. Technical realization

Next to the installation of a permanently fully functional *Building Monitoring System* main aspects of the technical realization are the safety and protection of the instruments. This was locally achieved by the following measures [*EDAC 2006*], compare also with Figure 4:

- inaccessibility (installation on the roof and in unused building niches),
- lockable boxes made out of stainless steel (for the free field stations) or aluminum (inner/on the building) to protect the instruments against environmental conditions, vandalism or objects, which may fall on it,
- a protected inaccessible laying of the cable as far as it was possible. Cables laid into the ground were protected by PE pipes (as protection against rodents and excavations). Inside and on top of the buildings the cables were laid into PVC tubes or hoses.

4.3. Measured Events

During the period of operation between September 09, 2006 and May 15, 2007, around 57 local events with magnitudes M ≥ 3.0 occurred within a 200 km epicentral distance R_e. As Figure 5b shows, 14 of these events could be recorded by the instrumented school building (BMS-1) and some of them by the other instrumented buildings (BMS-2 and BMS-3). Table 4.1 specifies the details of the recorded earthquakes and marks those recorders (MR*i*) registering the event. The given values express the amplification of the ground acceleration in x-direction related to the free-field station. The level of ground motion of the measured earthquake at the free-field station is indicated by different colors. The maximum recorded acceleration is 4.4 mg at BMS-2 (EQ No. 2).
The fact that the events could not be recorded by all instruments is resulting from the chosen instrumentation scheme especially at BMS-3 (Akdeniz Apartman). Due to accessibility reasons the master instrument was placed outside of the building establishing the free-field station. Because of disturbances directly at the station being caused by pedestrians the level of threshold trigger was stipulated at 5 mg. This leading to the circumstance that a passive trigger of instruments MR2 (basement), MR3 and MR4 (both top) is prevented for those events having smaller free-field accelerations than 5 mg. Therefore, all recordings at BMS-3 were actively triggered by the respective instrument. Meanwhile the instrumentation scheme could be changed by using a w-lan adapter to communicate with the master instrument in order to record more seismic events in the future also at this building.

4.4. Analysis and interpretation of the recorded data

The reliability of the recorded data is ensured after several sensor and signal controls. By calculating the response spectra out of the recorded events it can be seen that a characteristic building period and hence a usual building reaction occurred despite the fact that the building was only excited by weak motions.

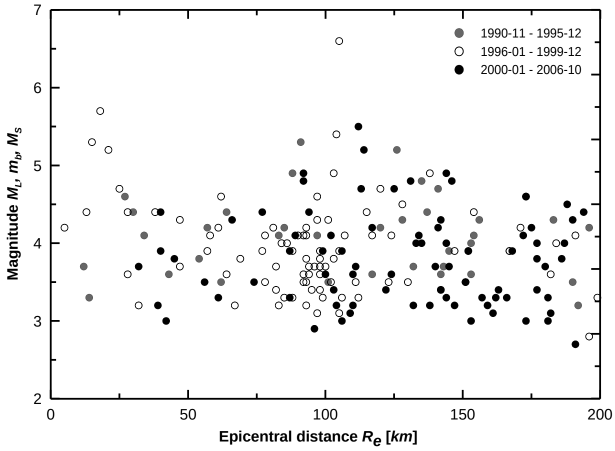
Table 4.1 Parameter of the recorded events and indicating the availability of data of each sensor

No.	Date	Time	Location		h [1]	M	R_e [3]	Recorded [4]											
			Lat.	Long.	[*km*]		[*km*]	BMS-1				BMS-2				BMS-3			
								1	2	3	4	1	2	3	4	1	2	3	4
1	19.09.06	03:28:52	35.947°	35.772°	21.6	3.8	45.9	3.1	3.0	1.1	1.0	4.8	3.6	1.0	- [2]	-	o	o	o
2	09.10.06	08:01:34	35.824°	35.600°	39.0	4.3	66.6	5.0	5.1	1.1	1.0	1.8	1.7	0.6	1.0	-	o	o	o
3	26.10.06	23:08:45	35.963°	36.280°	18.0	3.1	30.6	4.5	4.8	0.9	1.0	-	-	-	-	-	-	-	-
4	26.10.06	23:43:19	35.969°	36.138°	17.3	3.0	27.9	3.8	3.9	1.0	1.0	-	-	-	-	-	-	-	-
5	24.11.06	13:33:41	37.070°	36.160°	12.0	3.6	94.5	3.0	2.9	0.8	1.0	1.5	1.4	0.5	1.0	-	-	-	-
6	07.01.07	13:10:35	37.133°	36.092°	20.5	3.9	101.7	2.8	2.5	0.8	1.0	-	-	-	-	-	-	-	-
7	25.01.07	10:04:03	36.117°	35.897°	17.2	3.0	25.9	4.6	5.1	1.2	1.0	1.1	0.9	1.0	- [5]	-	-	-	-
8	02.02.07	01:04:15	35.839°	35.901°	11.9	3.6	48.1	4.0	4.0	1.2	1.0	1.3	1.2	0.7	1.0	-	-	o	o
9	03.02.07	09:03:00	36.946°	35.419°	27.4	3.6	104.2	3.0	3.1	1.0	1.0	1.8	1.4	0.5	1.0	-	-	-	-
10	11.03.07	22:11:47	36.557°	35.877°	6.3	3.8	45.0	2.9	2.9	1.1	1.0	1.3	1.3	0.6	1.0	-	-	-	-
11	14.03.07	22:18:31	36.472°	35.858°	4.5	3.2	38.7	2.2	2.1	0.9	1.0	1.1	1.4	0.5	1.0	-	-	-	-
12	07.05.07	01:56:25	36.835°	35.576°	21.6	3.8	85.8	2.6	2.5	1.0	1.0	2.4	2.1	0.7	1.0	-	-	-	-
13	12.05.07	16:06:40	36.386°	35.634°	7.6	3.8	50.3	3.5	3.2	0.9	1.0	1.0	1.0	0.4	1.0	-	-	o	o
14	15.05.07	05:16:31	35.967°	35.826°	4.7	3.1	40.8	2.4	2.1	0.8	1.0	1.0	0.8	0.6	1.0	-	-	-	-
:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:

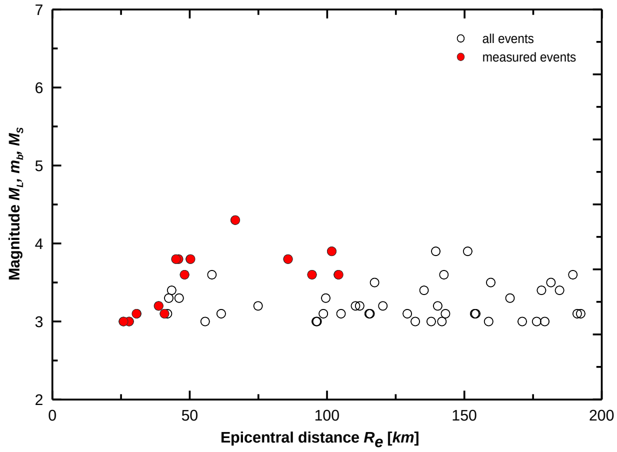
[1] h – focal depth
[2] due to hardware problems (defective sensor) a recording was not possible
[3] distances were calculated to the school building BMS-1
[4] amplification of the ground acceleration in x-direction; for BMS-3 only the recorded data were indicated by o
[5] recording was superimposed by noise

$a < 0.5$ $0.5 \leq a < 1.0$ $0.5 \leq a < 1.0$ $3.0 \leq a$ [mg]

The recorded ground motion and building response accelerations were first analyzed by calculating the response spectra as well as the spectral relations between top and basement in each direction separately. Figures 6 a) and b) show the spectral accelerations of the M 4.3 earthquake (see Table 4.1 - No. 2) recorded at BSM-1 (school) and the spectral relations (amplification) between the roof (CH 1 and CH 4) to the basement (CH 7). Figures 6 c) and d) illustrate the analyzed fundamental periods T (distinctive peak in the spectral relation) of both buildings (BMS-1 and BMS-2) for each record, respectively.
It can be seen, that the fundamental period of the school building (BMS-1) is supposed to be a torsional mode shape. This is indicated by the same position of gray dots and blue squares. The strength of the earthquake so far obviously has no impact on this behavior since no stronger earthquake occurred until now. It is remarkable to see the different behavior of the buildings in terms of amplification and the different levels of ground motion at each building site. The latter being influenced by different epicentral distances, directivity of the earthquake ground motion and local subsoil conditions at the two building sites. At both buildings (BMS-1 and BMS-2) effects of soil structure interaction can be observed.

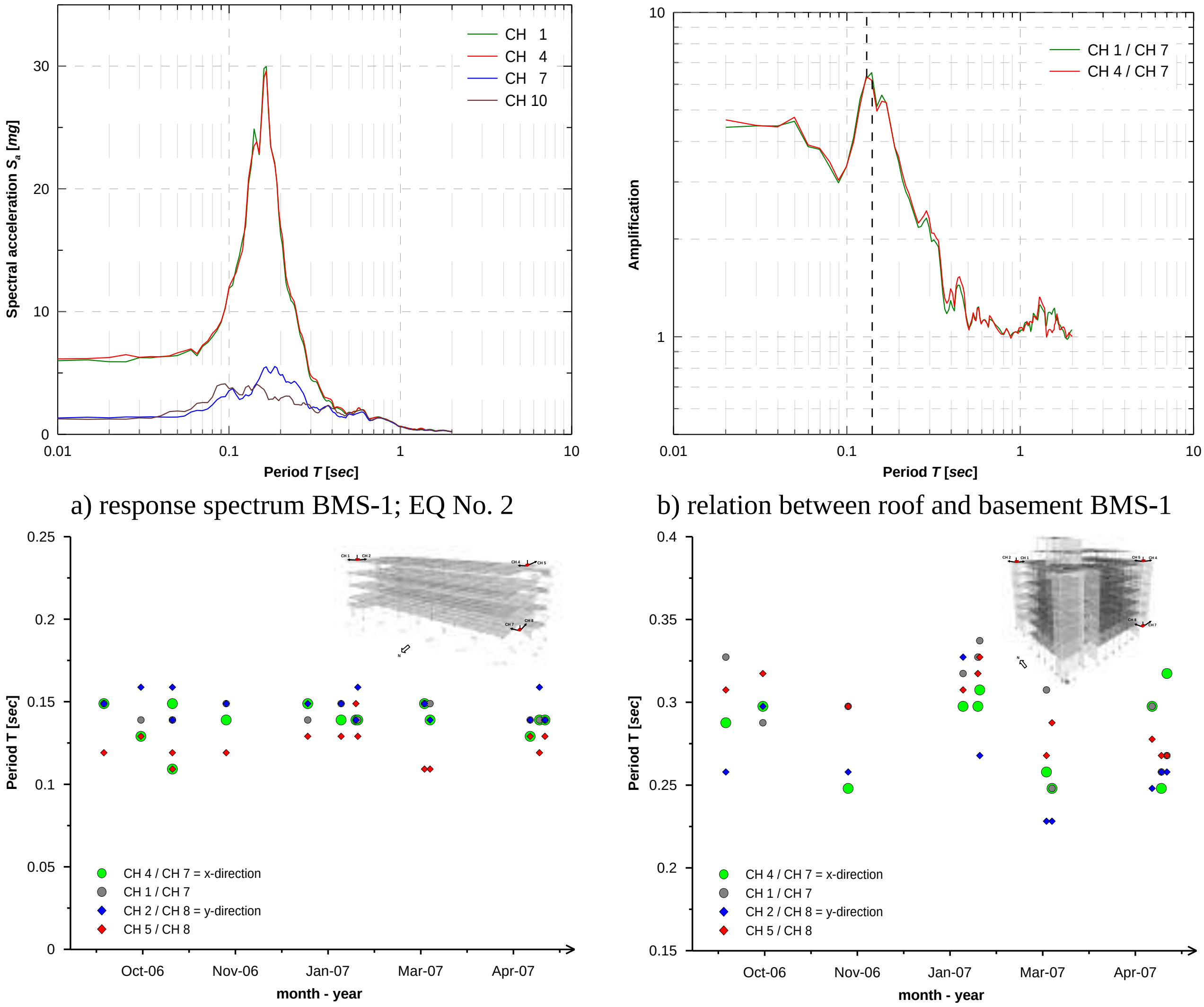


a) 11.1990 – 10.2006



b) 10.2006 (start of the BMS) –

Figure 5 Recent earthquakes within 200 km radius around Antakya; data from [*KOERI*]



a) response spectrum BMS-1; EQ No. 2 | b) relation between roof and basement BMS-1

c) Periods of BMS-1 | d) Periods of BMS-2

Figure 6 Periods derived from recordings (Table 4.1) in chronological order

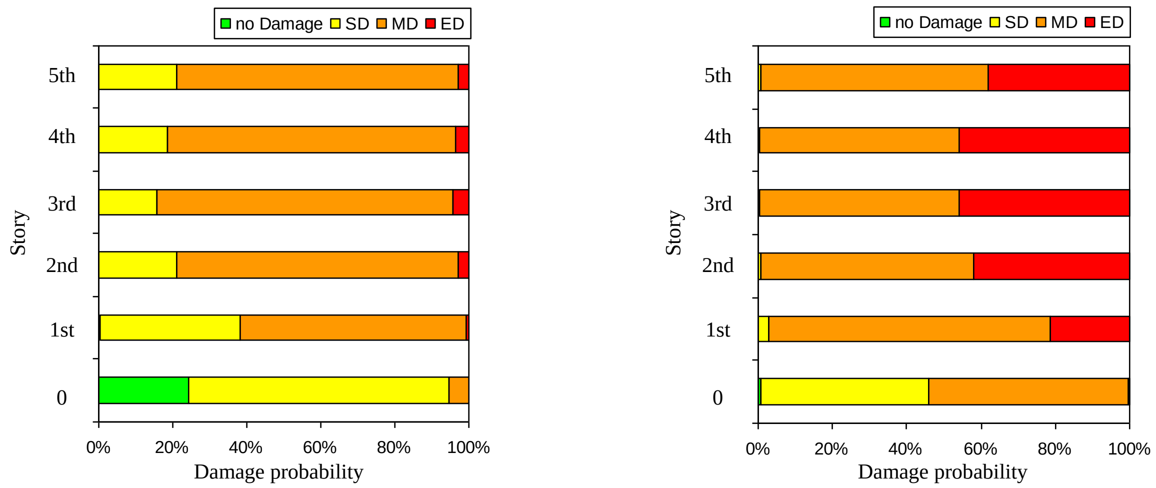
5. CONCLUSIONS

The presented data confirms the fact that the region around Antakya will be afflicted by stronger events (see Figure 5a). This means, in a relative short time window (scheduled are 3 years) it is possible to collect data, which will allow beside the interpretation of the dynamic building characteristic also to make competent statements to the behavior under seismic waves, influence of structure-soil interaction and local site effects, respectively.

The comparison between the recorded events and the first analytical investigations illustrates that the structural models do not correspond with the reality and a calibration of the material properties as well as model assumption is necessary. To complement the data in terms of building response it is intended to conduct additional instrumental investigations at selected existing buildings in the framework of a further project (*Damage and seismic response prognosis for RC frame structures on the basis of hybrid approach combining instrumental and numerical data*). Especially to calibrate the structural models and the assumption of the used material properties. This will be done by the artificial excitation of the building and the real-time recording of the structural behavior on several building points. Further investigations will concentrated on the damage prognosis for the instrumented structures and the transfer of the results into the seismic risk assessment.

The three already instrumented structures represent typical buildings of Antakya and single types of the

presented building typology of the whole reinforced concrete building stock. Whereby a first reliable basis is created for the damage prognosis of these types of structures.
In the next steps, the hybrid concept to use a reduced complexity seismic *Building Monitoring System* to evaluate the current state and damage prognosis of a building stock needs the comparison of the instrumentally (real) with the analytical determined response parameters (*Hybrid Method for Pre-Earthquake Damage Quantification of Instrumented Buildings*). On the basis of the recorded earthquakes, calibrated models, ground-motion prediction relations as well as the knowledge about stronger previous earthquakes (see Figure 5a) a damage prognosis can be conducted for different scenario earthquakes. By using the approach of [*Naeim et al., 2005*] and the maximum determined interstory drift under the scenario earthquake, damage prognoses can be carried out (see Figure 7) and to further enhance it by analytical investigations.



a) M = 6.7 / R_e =1.0 km b) M = 7.5 / R_e = 2.0 km

Figure 7 Damage probability for scenarios referring to historic events (1872, M=7.5, Re = 4 km); east/ west component; [SD, MD, ED = **S**light, **M**oderate, **E**xtensive **D**amage]

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