LESSONS FROM RECENT EARTHQUAKES – FIELD MISSIONS OF GERMAN TASK FORCE

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SUMMARY

The paper gives an overview of the last field missions of the German TaskForce Group and presents exemplary results of the engineering analysis, which consists mainly of aftershock measurements, macroseismic studies and re-interpretation of earthquake damage. Furthermore it should contribute to assess the quality of available data collected during post-earthquake missions.

The results shown in this paper mainly trace back to the field works conducted in Antofagasta (Chile, 1995), Cariaco (Venezuela, 1997) and Adana/Ceyhan (Turkey, 1998). The data of aftershock measurements is mainly used to evaluate local site amplification potential as well as to achieve detailed information about subsoil, such as predominant site frequencies. Macroseismic studies in urban areas, e. g. the performance of questionnaires, considering different building types and vulnerability classes as well as different damage grades and adopting the European Macroseismic Scale (EMS-92, EMS-98), were used for intensity evaluation and definition of vulnerability functions for different building types. The interpretation of a selected damage case is presented for the 1997 Cariaco (Venezuela) earthquake (07/09/97, M_s = 6.8), which stresses deficiencies in design and member detailing.

INTRODUCTION

The German TaskForce for Earthquakes is a cooperation of earth scientists (geophysicists and seismologists), structural engineers and re-insurance companies, whose purpose is to coordinate the rapid deployment of experts and technical equipment to areas affected by strong earthquakes, especially into those countries with need in recording equipment and technical support. The main aim is to collect data immediately after the occurrence of an earthquake in order to carry out fundamental research work and minimize earthquake peril to the population and structures [2].

Table 1 provides an overview of all post-earthquake missions with seismological recordings taken place since the year 1992 into different countries and presents the amount of seismic equipment involved with basic investigation results. A more detailed assessment of the various missions containing information of interest to the engineer is shown in Table 2, illustrating also the increasing intensity of research activities over the years. This is especially visible in the supplementary mission in spring 1999 into the earthquake area in Northeastern Venezuela, which was undertaken in order to collect missing data used for innovative analysis methods and to document local alterations, like strengthening and repair of damaged buildings.

RECORDING SITES, AFTERSHOCK DATA AND SITE RESPONSE STUDIES

Subsequently, the events in Antofagasta (Chile, 07/30/95, M_s = 7.3), Cariaco (Venezuela, 09/07/97, M_s = 6.8) and Adana/Ceyhan (Turkey, 06/27/98, M_s = 6.2) are used for application of different methods of analysis to achieve information about subsoil properties of the regarded recording sites. The recorded aftershock data, which

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consists of three-component time-histories, is transferred to the frequency domain, like response spectra or Fourier amplitude spectra. Furthermore these spectra are processed into H/V-ratios, which result from the division of the horizontal by the vertical component of motion. The comparison of the different shapes of spectra, their H/V-ratios and, if informations of local subsoil properties are available, the generated amplification functions (transfer functions) help to identify the potential of seismic amplification and the range of predominant site frequencies.

Table 1: Aftershock studies of German TaskForce for Earthquakes since 1992

Event	Type of Event	Recording Time	Seismic Stations	Strong Motion Stations	Aftershocks with ML>3	Results
Erzincan Turkey 13.03.1992 MS = 6.8	intraplate event trike-slip mechanism	21.3. - 16.6. 1992	10	-	52	tectonic model of the Erzincan basin
Killari/ Latur India 29.09.1993 MS = 6.3	intraplate event strike-slip mechanism	8.10. - 20.1. 1993	12	4	3	identification of active fault, strong ground motion amplification
Antofagasta Chile 30.07.1995 MS = 7.3	subduction zone thrust mechanism	10.8. - 2.10. 1995	39 1)	6	166	b-value mapping, damage analysis
Cariaco Venezuela 09.07.1997 MS = 6.9	intraplate event strike-slip mechanism	18.7. - 22.8. 1997	18	10	32	fault segmentation, site studies, macroseismic investigation, damage analysis
Adana (Ceyhan) Turkey 27.06.1998 MS = 6.2	East Anatolian Fault strike-slipmechanism	5.7.-10.8. 1998	-	10	162)	damage analysis, site studies

[1] Joint Project with the Co-operative Research Centre "Deformation Processes in the Andes"
[2] AFET Ankara, Turkey

Table 2: Objects of investigation

	Task Force Missions					
	1992	**1993**	**1995**	**1997**	**1998**	**1999**
	Turkey	**India**	**Chile**	**Venez.**	**Turkey**	**Venez.1**
Involved engineers in the missions	**1**	**1**	**1**	**3**	**2**	**3**
Engineering analysis of structural damage						
Strong-motion data from aftershock records	-					-
Macroseismic studies and intensity assessment		-				-
Site response studies using site profiles				-		-
Microzonation using intensity assessments	-	-	-		-	-
Microzonation using ambient noise data				-	-	
Re-interpretation of selected damage cases	-	-	-			
Vibration measurements of structures	-	-	-	-	-	

in more   **medium**   **less**   **detail**   **[1] post-TaskForce Investigation**

RECORDING SITES, AFTERSHOCK DATA AND SITE RESPONSE STUDIES

Subsequently, the events in Antofagasta (Chile, 07/30/95, M_s = 7.3), Cariaco (Venezuela, 09/07/97, M_s = 6.8) and Adana/Ceyhan (Turkey, 06/27/98, M_s = 6.2) are used for application of different methods of analysis to achieve information about subsoil properties of the regarded recording sites. The recorded aftershock data, which consists of three-component time-histories, is transferred to the frequency domain, like response spectra or

Fourier amplitude spectra. Furthermore these spectra are processed into H/V-ratios, which result from the division of the horizontal by the vertical component of motion. The comparison of the different shapes of spectra, their H/V-ratios and, if informations of local subsoil properties are available, the generated amplification functions (transfer functions) help to identify the potential of seismic amplification and the range of predominant site frequencies.

Antofagasta (Chile) earthquake of July 30, 1995

The epicenter of the magnitude $M_s = 7.3$ ($M_L = 6.8$) earthquake was located in the north of the town Antofagasta. On the basis of the European Macroseismic Scale EMS-92 [Grünthal et al., 1992] a maximum intensity I = VIII was assigned [Schmidt et al., 1995]. Due to the fact that most parts of the city are situated on bedrock or thin layers of sediments over bedrock, the dimension of building damages was generally low. After the mainshock more than 50 aftershocks with magnitudes $3.0 < M_s < 5.4$ were recorded by six strong-motion accelerographs, the positions of which can be seen in Figure 1.

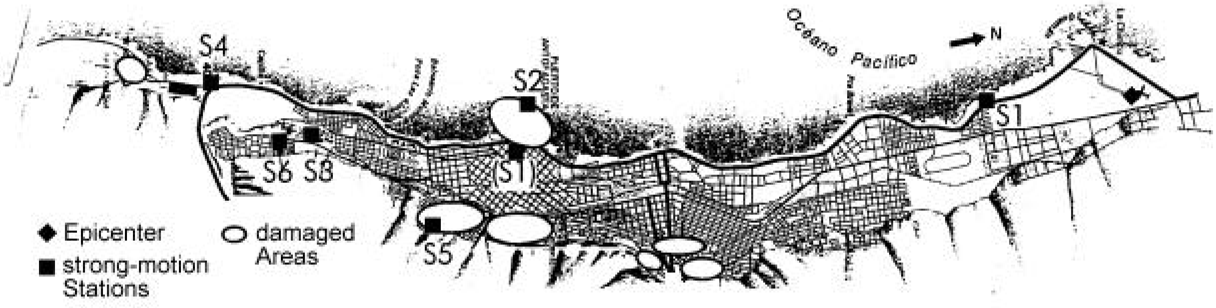

Figure 1: Temporarily installed strong-motion stations in the urban area of Antofagasta (1995)

The time-histories of one of the strongest aftershocks with magnitude $M_s = 4.8$ at station 5 and 6 are presented in Figure 2a. These two stations were placed in a distance of only 3 km and were regarded to possess the same subsoil conditions: a soft sediment layer ($v_s = 250$ m/s) of 7.5 m (Station 5) resp. 5 m (Station 6) thickness over halfspace (volcanic andesit, $v_s = 1.500$ m/s). The comparison between the shapes of Fourier spectra (Figure 2b) as well as the amplification functions (Figure 2c) of both stations demonstrates that the predominant periods of station 5 are shifted into the long-period range. Moreover, the higher level of amplitude of Fourier spectra for station 5 verifies the information about local subsoil properties, which predicates a thicker sedimentary layer at station 5.

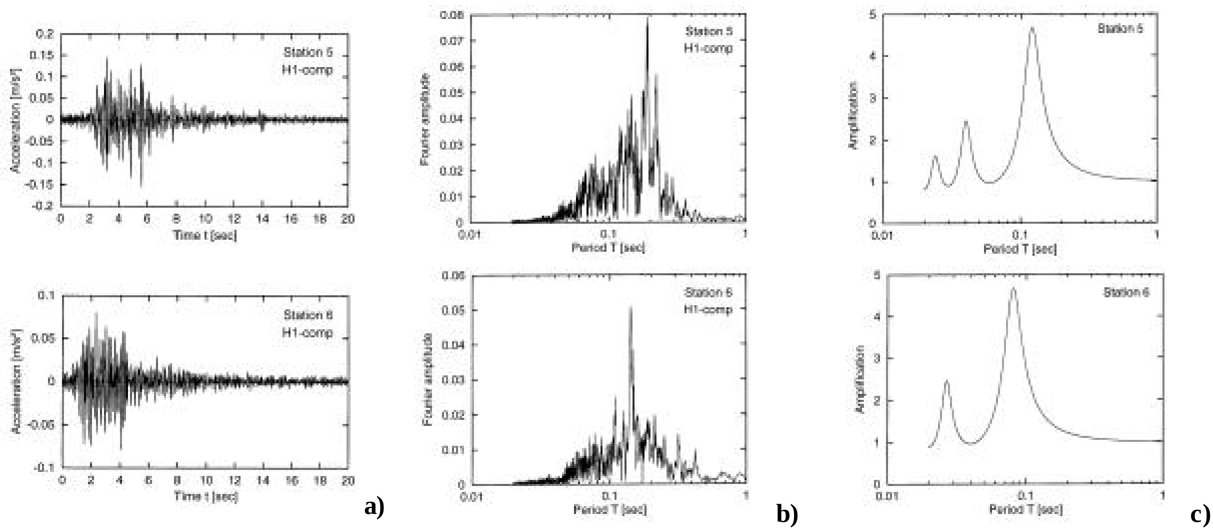

Figure 2: Aftershock of August 18, 1995, 06:37 UTC at stations 5 and 6: time-histories (a), their FFT-spectra of the stronger horizontal component (b) and transfer functions of the subsoil profiles (c)

Cariaco (Venezuela) earthquake of July 09, 1997

A few days after the mainshock ($M_s = 6.8$) 10 strong-motion recorders were installed in the disaster-struck area close to the Caribbean coast of Northeastern Venezuela (see Figure 3). During the whole investigation period of

35 days about 77 aftershock events, with local magnitudes of up to 4.6, were registered [Schwarz et al., 1998][Lang et al., 1999]. Because detailed information about local subsoil properties, such as from borehole samples, were not available, site response studies concentrate more on aftershock data as well as ambient noise measurements, which were carried out during a second mission in spring 1999. Figures 4-6 show results of aftershock data only. The strongest event occurred exactly 3 weeks after the main shock with a magnitude M_L = 4.6 and reaching peak ground accelerations of up to 0.25 g. Its normalized response spectra of the stronger horizontal component at each of the 7 recording stations are given in Figure 4.

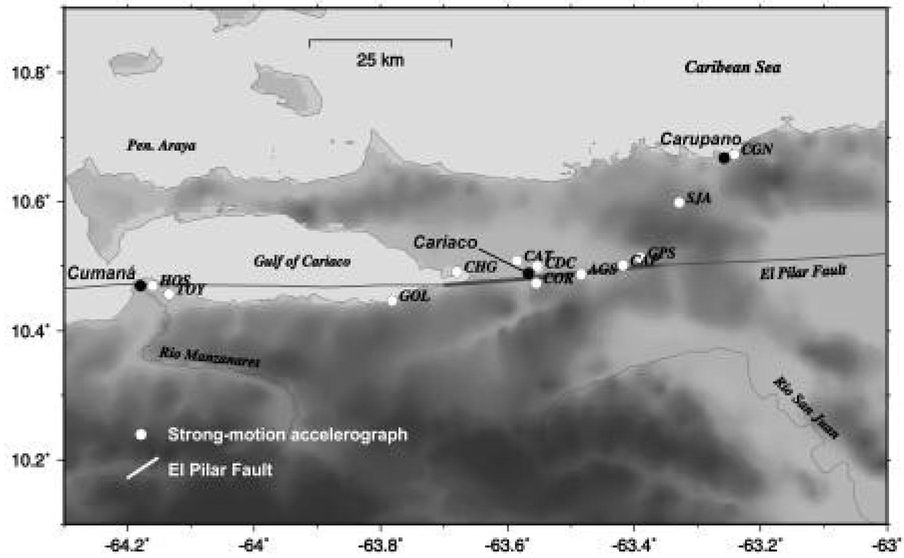

Fig. 3: Map of the affected area in Northeastern Venezuela and sites of the strong-motion accelerographs

On the basis of aftershock events with magnitudes M_L > 3.0 a site response study is presented in Figures 5 and 6 for station El Cordon (COR), as an example. A comparison of the shape of response spectra, shown in Figure 5, the horizontal-to-vertical ratio of response spectra (Figure 6a) and the H/V-ratios of Fourier amplitude spectra (Figure 6b), can not clearly identify a predominant period at 0.15 s. The estimation of station El Cordon to be situated on rock could be verified by the results, that no clear peaks are developed in the H/V-ratios. It is the task for ongoing investigations to study the different analysis methods more deeper in order to determine the predominant periods unambiguously.

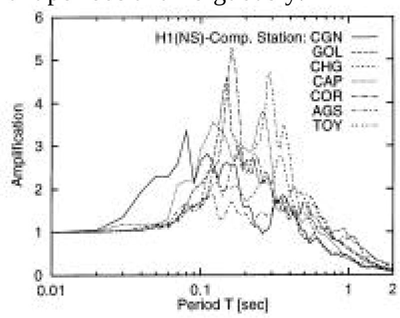

Figure 4: Normalized response spectra of the strongest aftershock on July 30, 1997 with ML = 4.6 at the different recording stations

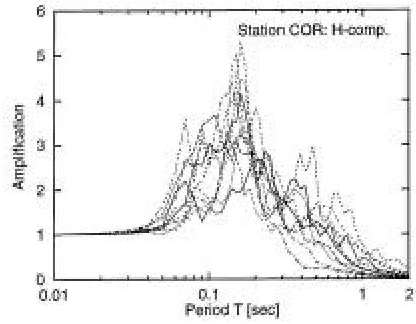

Figure 5: Normalized response spectra of the horizontal components of aftershocks with magnitude ML > 3.0 recorded at station El Cordon

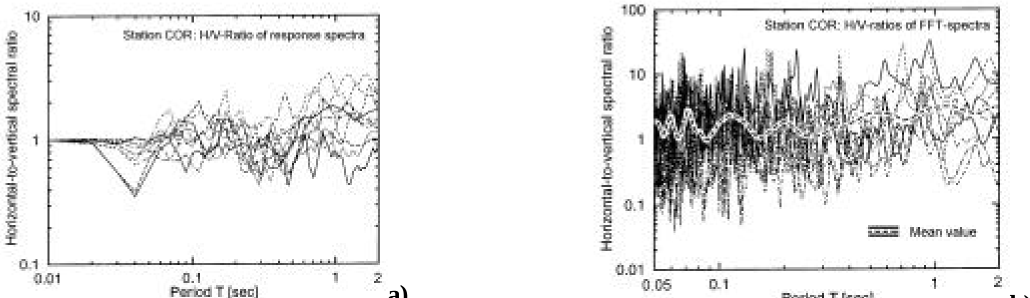

Figure 6: Horizontal-to-vertical spectral ratios at station El Cordon (COR) using a) response spectra and b) Fourier amplitude spectra (FFT) of aftershock data with ML > 3.0

Adana/Ceyhan (Turkey) earthquake of June 27, 1998

The magnitude M_w = 6.3 earthquake happened in the southern part of Turkey, about 30 km to the north from the Mediterranean Sea coast. Astonishingly, local buildings suffered only moderate damage, though a maximum intensity of the quake was estimated to reach I (EMS) = IX [Wenk et al. 1998]. The recording of 41 aftershock events during the 2 week lasting period was ensured by the installation of 9 strong-motion accelerographs. The computed transversal time-histories of a strong aftershock at stations Gotlu and Hakkibeyli is shown in Figures 7a. Furthermore Figures 7b and 7c illustrate response spectra and Fourier amplitude spectra, respectively, of both horizontal directions (NS, EW) as well as their derived transversal (T) and radial (R) directions.

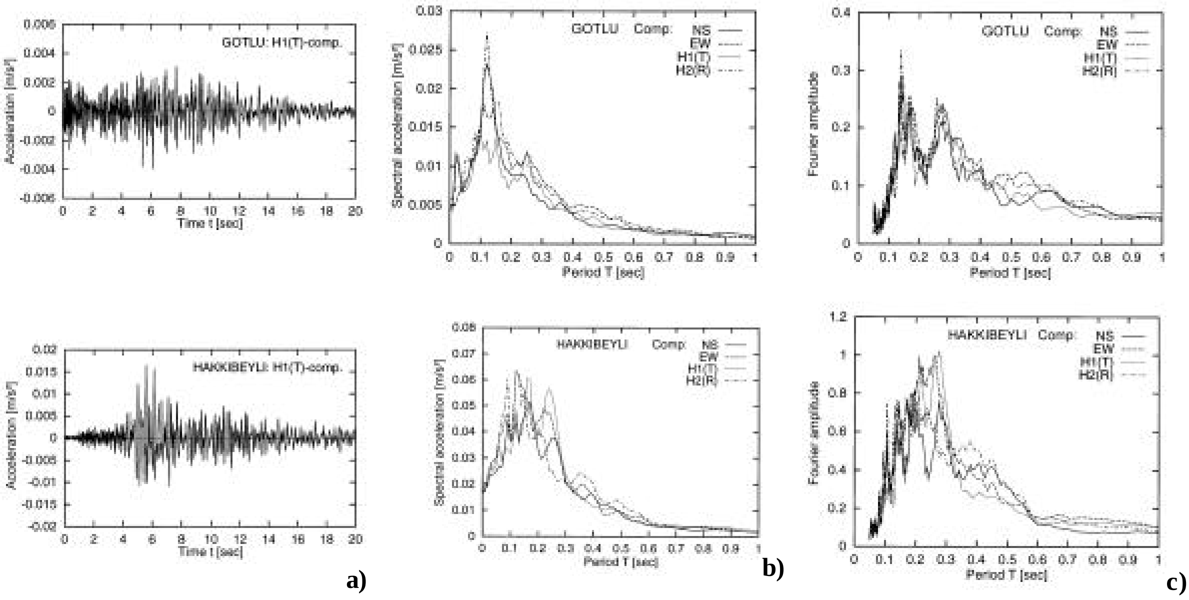

Figure 7: Strong-motion data of a strong aftershock event (07/13/98, 10:44 UTC, Ms = 3.5) at stations Gotlu (rock site) and Hakkibeyli (alluvium site): a) time-histories of the transversal component H1(T), b) response spectra of all horizontal components and c) Fourier amplitude spectra from

A more detailed site study of station Abdioglu is presented by Figures 8. The comparison between Fourier amplitude spectra, separately computed for the strong-motion phase (Figure 8a) and the pre-event noise (Figure 8b) and their resulting H/V-ratios, shown in Figure 8c, could identify predominant site-periods at 0.15 - 0.30 s. This fact is also verified by the shape of response spectra of horizontal components (see Figure 8d) and the additional computed amplification function of the sites' subsoil (Figure 8e).

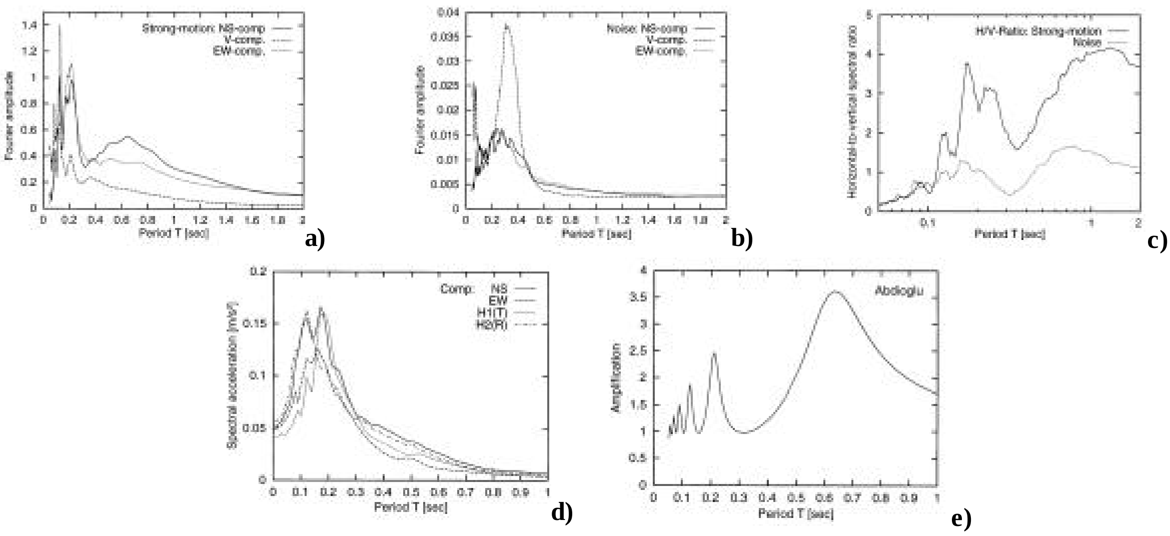

Figure 8: Site studies of station Abdioglu: Fourier amplitude spectra of a) the strong-motion phase, b) the pre-event noise and their corresponding horizontal-to-vertical spectral ratio (c), d) response spectra of horizontal components, e) period-dependent transfer function of the local subsoil profile

MACROSEISMIC INVESTIGATIONS

Intensity assignments and microzonation

During the first TaskForce missions only rough estimations of intensities were made, just distinguishing buildings into several types. Within the 1997 mission in Cariaco (Venezuela), an exceedingly comprehensive assessment of intensity distribution was carried out. As can be seen in Figure 9, an intensity map on basis of a comprehensive questionnaire was drawn up for the urban region of the town Cumaná. The intensity map, established using a Geographic Information System (GIS) and regarding the European Macroseismic Scale [Grünthal et al., 1993, 1998], is based on smoothed neighborhood data. Nevertheless, the missing of datapoints in sparsely populated areas, complicates a reliable intensity estimation in those areas.

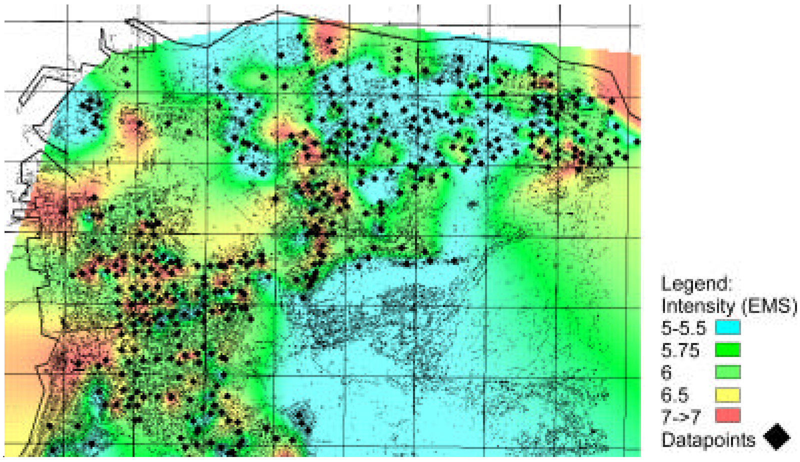

Figure 9: Intensity map of the town Cumaná with neighborhood analysis

Vulnerability functions within the European Macroseismic Scale (EMS-92, EMS-98)

Within the EMS, in addition to the extent of suffered damage, buildings are divided into different vulnerability classes. In case of the Cariaco-earthquake in 1997, the local building types, e. g. RC-frames and confined masonry have to be assigned to a vulnerability class, first. This should already be made, when regarding the grade of the buildings' damage. As the results are sorted into vulnerability functions of passed earthquake analysis (see Figure 10), these evaluations must be assigned approximately. Of course, local spectra of ground motion as well as local site amplification potential have to be considered just as much as the results have to be compared with other methods of intensity analysis. Furthermore these results could be used for an empirical database concerning risk estimation.

During the already mentioned macroseismic studies in Cariaco-area, vulnerability functions were generated for several building types. Figure 10 shows the datapoints for two-story RC-frame buildings, compared with vulnerability functions according to EMS [3]. By regarding the positions of the building-types' datapoints, RC-frames can be assigned into vulnerability class B(C). Generally spoken, the intensities derived from building damage (EMS) are mostly situated in the range of expectation of those evaluated by other studies.

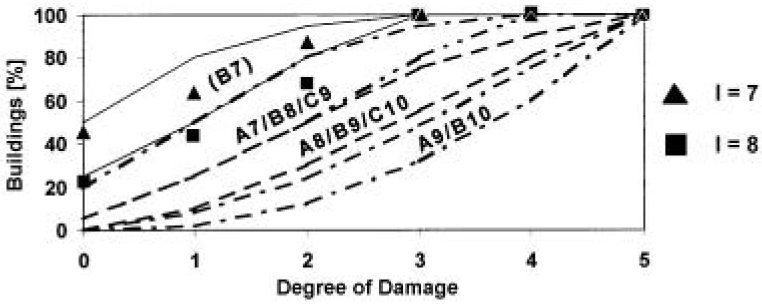

Figure 10: Damage distribution of two-storey RC-frame buildings in Venezuela with different local intensities compared with vulnerability functions according to damage surveys

ENGINEERING ANALYSIS OF STRUCTURAL DAMAGE

To allow a better understanding for structural damage and failure mechanisms caused by strong earthquakes, it is of importance to carry out detailed investigations of buildings which have suffered earthquake damage.

Beginning with the documentation of the building itself including the location and amount of its structural and non-structural damage, the procurement of the building plans and material samples can be helpful for the development of computer models and for the investigation of damage reasons. The received results can further be supplemented by vibration measurements of the regarded buildings, in order to identify the buildings dynamic characteristics.

This was realized for this first time in 1999 during a post-TaskForce mission into the earthquake area of Northeastern Venezuela. The figures below (Figures 11 and 12) demonstrate some results of a four-storey residential building in Cariaco, which had been seriously damaged during the 1997-earthquake. Especially large parts of the infill brick masonry walls, situated between the RC-frames, dropped out (Figure 12) at one buildings' end. A water tank being placed on the top of that part of the building probably caused these damages. This could also be concluded from the fact that similar structures without such water containers standing nearby suffered no damages at all. Therefore, it could be assumed that the additional mass of the water tank provoked a serious eccentricity to the structure, thus leading to the damages.

Figure 11: View of the repaired south facade of the building "Los Bloques" (photo taken in 1999)

Figure 12: Damaged south-eastern corner of the building after the 1997 earthquake

A simplified computer model of the structure on basis of the in-situ documentation indicated a predominant dynamic response of the building in the transversal direction (Figure 13), especially at those areas of the structure, where most damages were located.

Further vibration analyses of the repaired building in 1999 detected its eigenfrequencies. The spectral ratios of amplitudes of data of measuring instruments (three-component, low frequency geophones) with the same direction but different storeys is given in Figure 14, which identify the first vibration mode in the transversal direction (f_1 = 4.3 Hz), the second mode in the longitudinal direction (f_2 = 5.8 Hz) and the third mode in the torsional direction (f_3 = 6.3 Hz).

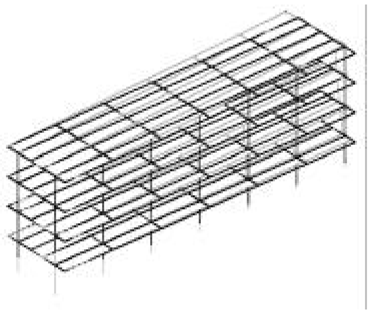

Figure 13: First vibration mode shape of a computed model in the transversal direction

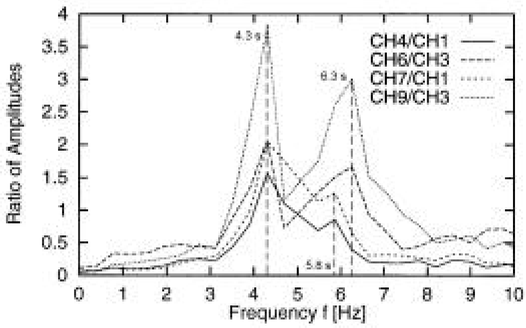

Figure 14: Ratios of amplitudes between different sensor channels to identify the eigenfrequencies

Microtremor observations [Masaki et al., 1997] detected a predominant site frequency in the range of 3 – 5 Hz, which could also be an indication for damage, deriving from resonance effects between building and site frequency. These investigations should be supplemented by the results of recently carried out ambient noise measurements in and around the town Cariaco, during the post-TaskForce mission in 1999 (PETFINEV-99).

CONCLUSIONS

1. If sufficient recordings of mainshocks are not available, the feasibility of aftershock measurements can be an extraordinary tool in order to allow a re-interpretation of earthquake damage.

2. The application of capable methods on aftershock data can be used to detect informations about local subsoil accurately, like site amplification potential as well as predominant site frequencies.
3. The additional use of different types of seismic data, e. g. recordings of strong earthquakes, aftershocks and ambient noise, can be helpful to verify the different methods.
4. The different methods to evaluate local subsoil properties are required further investigations concerning the type of input signal.
5. The results of these site studies can further be used to supplement macroseismic evaluations, as well as seismic risk assessment.
6. Macroseismic studies, like for example an intensity estimation by the realization of questionnaires, seem to be an excellent empirical base for risk estimations.
7. An intensive documentation of real suffered earthquake damage, including the analysis of material specimens, successfully combined with numerical studies as well as the results of dynamic vibration measurements, can lead to the re-interpretation of earthquake damage or failure mechanisms and can also be used to prove the results of the individual damage surveys.
8. Aftershock data, recorded at sites of damaged buildings, can be used to check national earthquake-resistant regulations as well as the degree of an anti-seismic design of particular buildings.

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21. The authors would like to thank the Hannover Rückversicherungs AG Eisen und Stahl for co-sponsoring TaskForce missions since the year 1994.