13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 1947

UNCERTAINTIES IN EARTHQUAKE SCENARIOS

Sibylle STEIMEN[1], Donat FÄH[2], Martin BERTOGG[3], Silvio TSCHUDI[3] and Domenico GIARDINI[4]

SUMMARY

Earthquake Scenarios are an important instrument to evaluate earthquake risk in urban areas. In regions where single major earthquakes dominate the overall hazard, the only information on these events dates often back to historical times, leading to a high level of uncertainty of the input parameters in earthquake scenarios. The main goal of this study was the assessment of the level of uncertainty in input parameters as ground motion estimate, microzonation, inventory and vulnerability. Using the example of the historical earthquake in the city of Basel, Switzerland, in 1356 we modeled ground motion in terms of intensity. Seven different approaches (expert opinions) were used to derive the microzonation map to account for local site effects and their possible variability. We investigated the building types in the city based on a fast inspection from the sidewalk and cross correlated the results with reference data in order to quantify uncertainty and locate error sources. We developed an approach based on European Macroseismic Scale 1998 (EMS98) to derive vulnerability relations by modeling the fuzzy variables 'few', 'many' and 'most' as random variables. These are used in EMS98 to define for every intensity stage the amount of buildings of vulnerability A to F in the different damage degrees (DG1 to DG5). The final modeling process included Monte Carlo simulation of source parameters (location, magnitude, focal depth) and of the damage calculation procedure. For the other parameters such as microzonation and vulnerability/inventory a logic tree type evaluation was used to study their impact on the final results. The results of the different models highlight the importance of the inventory/vulnerability data and allow an evaluation of the relative importance of the single earthquake source input parameters.

[1] Swiss Seismological Service, Technoparkstr. 1, Einstein F29, 8005 Zürich, Switzerland. Email: sibylle@seismo.ifg.ethz.ch
[2] Swiss Seismological Service, Technoparkstr. 1, Einstein F29, 8005 Zürich, Switzerland.
[3] Swiss Reinsurance Company, Mythenquai 60/70, 8022 Zürich, Switzerland
[4] Swiss Seismological Service, Inst. of Geophysics, ETH Hönggerberg, 8097 Zürich, Switzerland

INTRODUCTION

Earthquake scenarios are a widely used tool, to investigate possible consequences on the built environment. Depending on the scope of a risk analysis, the tools differ in details they can resolve and parameters they need as an input. In general, all the earthquake scenario approaches lack from deficient input data due to incomplete knowledge of measured or assessed data.
Within the project presented here, we want to highlight these different aspects of uncertainty in earthquake scenarios. We present, two points of view corresponding to two different sub projects: the first part of this article gives a summary on a fast building inventory assessment. The main goal was the assessment of uncertainties in data assessment as well as in deriving the corresponding building vulnerability information. In the second part of this article the perspective is widened and we highlight uncertainties in a deterministic earthquake scenario approach.

UNCERTAINTY IN INVENTORY ASSESSMENT THROUGH FAST SCREENING

Introduction

The building inventory is one of the very crucial input parameters in an earthquake scenario. Depending on the type and quality of the buildings in the area of interest, ground motion of certain intensity can lead to complete destruction of the built environment or lead to only minor damage. This fact has found sad confirmation in December 2003 when two earthquakes in California and Iran having similar magnitude (M_w approx. 6.5) and comparable depth (approx. 8 km) but different fault mechanism (reverse vs. strike slip) lead to extremely different numbers of fatalities. Although other parameters than the building type (e. g. fault mechanism, directivity, time of the day, population density) will have played an important role, the unfavorable construction type of the buildings in the region affected most in the Iranian event had a big impact on the extreme death toll of over 30.000 people against only two persons killed in the Californian event where buildings are built to resist earthquake loads.
It is a common procedure to learn from past earthquakes and to use observed damage to derive the vulnerability of specific building types. In regions where major earthquakes are rare, we have no observational data of earthquake induced damages and therefore no possibility to derive empirical vulnerability curves for use within earthquake scenario tools. This lack of knowledge adds uncertainty to the scenario calculation process. The focus of our work is on a region where we have a typical low hazard but high risk situation. In Basel, Switzerland (Figure 3), the last major earthquake dates back to the year 1356, when an intensity IX event destroyed the city to a larger extent. Today the region is densely populated and hosts important industry facilities.
Two elements of uncertainty sources in inventories are investigated: those coming from the data assessment procedure and those from the translation of building information into vulnerability values.
In our first step we therefore developed and tested a procedure to rapidly assess vulnerability relevant building inventory data and derived building vulnerability from that data in our second step. Our method strictly follows a low cost strategy because in low hazard areas funds to finance building assessments are limited.

Building inventory and vulnerability assessment

Our approach to assess building data is similar to the one described in FEMA-154 [1]. We used a questionnaire to assess vulnerability relevant data of the buildings (Figure 1, left). The data assessment is based on a visual inspection from the sidewalk. This should allow the quick and therefore cheap data assessment foreseen. Neither studies of construction plans nor inspections of the interior was included in the data assessment process.

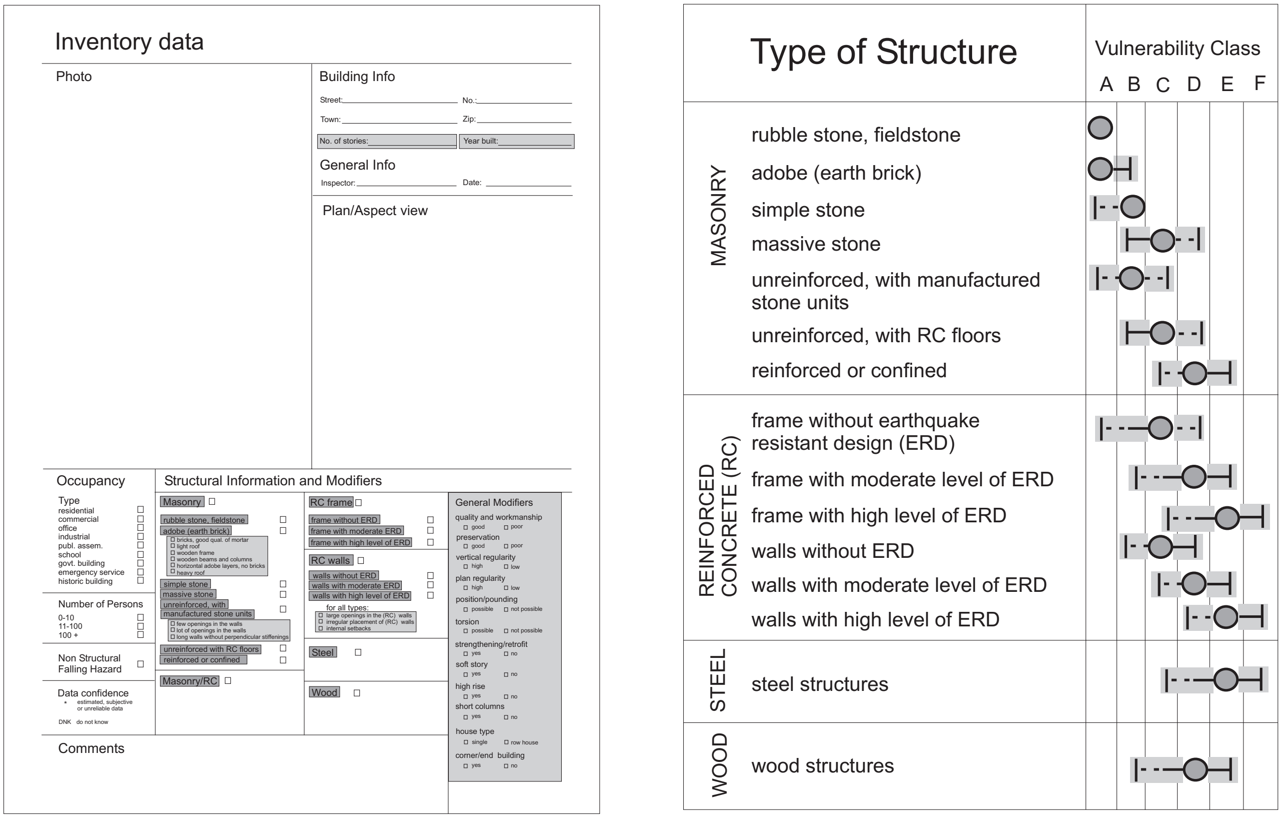

Figure 1 Inventory assessment questionnaire and the definition of building vulnerability in EMS98 with graphical link showing the information used to derive the vulnerability relevant information.

Three upper grade students worked for two weeks to compile the dataset. Half of the city districts (1 to 11, Figure 3) could be assessed on a spot testing basis. Spot testing areas consisted of whole street blocks and were pre-selected in the planning phase of the data assessment to represent the character of the corresponding city districts. 2190 building records of 1757 individual buildings were assessed and the parameters stored in the attribute database used in the vulnerability assessment process. The total number of houses in the database corresponds to approximately 10% of the overall building stock in the city.

The procedure used to derive vulnerability bases on the definitions in the European Macroseismic Scale of 1998 (EMS98) [2] (Figure 1, right). The scale defines for each common building type a 'base vulnerability' representing the mean vulnerability of the whole population of these buildings on a scale A to F; A having the least and F the best resistibility against earthquake actions. In Figure 1 the base vulnerability is indicated by the small circle in the 'vulnerability class' section. In addition to this mean value, a range of variability is given by error bars in solid (probable range) or broken (lesser probable range) lines. The range defines the possible values of vulnerability for *individual* buildings within the whole building class. The method to derive building vulnerability from the results of the fast screening assessment is indicated in Figure 1 using the graphical link between both parts of the figure. First, the 'base vulnerability' is defined based on the building type on the questionnaire (darker grey color). The building types correspond to the 'base vulnerability' marked by circles in the EMS98 definitions. Second, the final vulnerability is derived using information from the 'general modifiers' section on the questionnaire. This second step requires further explanation, since depending on the number and type of these modifiers plus and minus vulnerability steps have to be associated.

We used the following multi step approach to derive 'final vulnerability' from the inventory data (Table 1):

Table 1 Steps to derive final vulnerability using the general modifier parameters in the inventory

step	description
1	translating qualitative descriptions of modifier parameters into quantitative values
2	calculating a 'modifier parameter sum' representing the general condition of the building
3	A using arbitrary standard class width for the plus and minus vulnerability values OR
	B calibrating the 'modifier parameter sum' for the different building types using the definitions of EMS98 to get plus and minus vulnerability values
4	calculating final vulnerability values by combining 'base vulnerability' with the plus or minus vulnerability value derived in the three steps above

We used uniform weighting for all 'general modifiers' in the building questionnaire due to lack of observational data on damaged buildings during earthquakes in Switzerland. The qualitative description of a modifier can represent three conditions: a 'positive' effect on the earthquake resistance of a building, a 'negative' effect and a 'neutral' one (also representing the situation where the parameter could not be assessed). A modifier describing a 'positive' influence on the earthquake resistance was given a value of +1 (example: 'high plan regularity'); correspondingly a 'negative' one was given a value of -1 (example: 'low plan regularity'). If a modifier had an unknown or no effect on the earthquake resistance, a value of 0 was selected. The same value was used in cases, where we had a formally 'positive' condition but which did not improve the general condition or behavior of the building (examples: 'no soft story' or 'no short columns'). The 'modifier parameter sum' expresses a value for the general condition of the building (in addition to the construction type) and allows the definition of the 'final vulnerability' which should – when using the definitions of EMS98 - lie somewhere within the range of the error bar given. In order to define plus and minus vulnerability, we followed two different approaches. In the first one we used an arbitrarily defined standard key (the same for all building types) for the conversion of the modification parameter sum into plus and minus vulnerability: no change in the interval +/- 2, minus one or plus one in the range of -6 to -2 or 2 to 6 and for values higher and lower a change of two vulnerability stages was foreseen. In the second approach, the EMS98 definitions were used to derive building type specific modification sum ranges for plus and minus vulnerability. We used the terms 'probable' and 'less probable' as the ratio of houses for which the base vulnerability value is changed for the specific building type. We arbitrarily defined: 'probable' as 5 to 15%, 'less probable' as 1 to 5% and 'not existent' as < 1%. Figure 2 gives an illustration of this procedure for RC wall buildings.

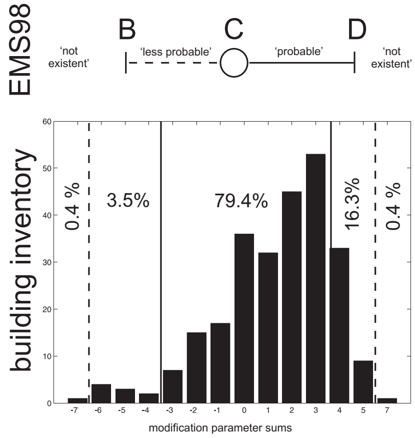

Figure 2 Calibration scheme of the modification parameter sum to the definitions of EMS98 (example for RC wall buildings)

Building Inventory and Vulnerability: Results and Reliability

Inventory Results

The buildings assessed in the inventory were mainly residential. Most buildings are up to 6 stories high (96%). For most buildings a construction year before 1969 must be assumed this means that they were built before the first earthquake code regulations were established in Switzerland in 1979 by SIA [3]. The great majority of the buildings are masonry (84%). 73% of these are unreinforced masonry (URM) constructions with timber or reinforced concrete (RC) floors. The remaining houses consist of rubble or simple stones. The second abundant building type in the data sample is RC wall buildings (12%).

Inventory Reliability

We used three different data samples to test the reliability of the inventory data. We had a reference dataset of a previous study by Lang [4]; second we had included double coverage in the data assessment procedure allowing testing the consistency of data assessment between the different building inspectors. Third we had a data set coming from the database of a building insurance which can be used as a reference for comparing the estimated year of construction parameter. The three datasets mentioned differ in the type of parameter they allow to test and the sample sizes which can be used for comparison.

The results of the test to the reference dataset coming from the previous study of Lang [4] are given in Table 2:

Table 2 Match of selected parameters to the reference dataset. The sample size was 74, 66 and 122 buildings for expert 1, expert 2 and expert3 respectively.

match to reference [%]	expert 1	expert 2	expert 3
year built (binned)	93	97	93
bins: < 1969; 1970 – 1989; >1989			
number of floors (binned)	99	97	97
bins: 1 – 3; 4 – 6; > 6			
construction type	66	42	39
construction type (binned)	72	52	50
bins: corresponding to same base vulnerability A to F			

Parameters which could be compared were: the ’year of construction’, ‘number of floors’ and ‘construction type’. We used binned data for the first two parameters with bin sizes which were later used in the procedure to convert building information into vulnerability. Here the match between the reference dataset and the results of all three experts is excellent. The match of the construction type is taken for binned and unbinned data and is only hardly satisfying. The match rises around 10% when using binned data. The rather low match between the reference and the expert data can be explained by the fact that it was difficult to distinguish certain building types from each other. Common problems involved the misidentification of the floor type in URM buildings which led to a shift in the ‘base vulnerability’ between B and C (both directions). Second it was difficult to distinguish rubble/field stone buildings from URM buildings with timber floors leading to a shift in the base vulnerability between A and B (both directions). And at last it was difficult to separate the RC/masonry building type from its end member RC wall buildings (corresponding to base vul. C) and URM buildings with RC floors (base vul. C). As it can be seen, only one common type of misinterpretation lies within a vulnerability bin this explains why the binned data does not show a significantly enhanced match. These common problems encourage the use of pilot studies prior to the full assessment of the inventory in order to find these problem cases. A possibility

to overcome them is the definition of additional architectural features helping in distinguishing the building types.
In our second test, we used the datasets for which more than one building expert had taken a record. This dataset was used to control the match between the ‘general modifier’ data which was unavailable in the previous analysis using the reference data set. The overall match is very good. The mean match for the parameters ‘occupancy’, ‘number of persons’, ‘quality of workmanship’, ‘preservation’, ‘plan regularity’, ‘torsion’, ‘strengthening, ‘soft story’, ‘short columns’ and ‘house type’ lied above 80%. Only for the two parameters ‘vertical regularity’ and ‘position pounding’ we had to note a lower match (77 and 60% respectively). The good match encourages the use of this data for vulnerability purposes.
The availability of a dataset by the ‘Kantonale Gebäudeversichrung’ of the Canton Basel-Stadt (building insurance company which offers the mandatory building insurance) made it possible to test the match of the ‘estimated year built’ parameter of larger data samples (sample size between 520 and 780 records) to a reference value. The match to the binned dataset was excellent (above 90%) for all building experts.

Vulnerability Results
We used six different methods to derive vulnerability from the building parameters collected. The six different data sets which resulted were then compared with each other and used in a scenario calculation procedure to demonstrate the impact of varying inventory parameters on the final scenario result. The different concepts are described in Table 3:

Table 3 Different methods to derive vulnerability from building parameters

method	description
1	inventory using the construction information only (‘base vulnerability’)
2	the same as approach 1 but using a priori information that no rubble/field stone buildings exists. Buildings in the database having this structural code were treated as ‘simple stone’ buildings
3	construction AND modifier information together with a *standard key* to convert modifier information into plus and minus vulnerability, using base vulnerability from method 1
4	construction AND modifier information together with a *standard key* to convert modifier information into plus and minus vulnerability, using base vulnerability from method 2
5	construction AND modifier information with a *building type specific key* to convert modifier information into plus and minus vulnerability, using base vulnerability from method 1
6	construction AND modifier information with a *building type specific key* to convert modifier information into plus and minus vulnerability, using base vulnerability from method 2

All above methods follow the general concept of deriving building vulnerability as defined in EMS98 by using fast screening parameter. They differ in the amount of data used (methods 1 and 2 omit the ‘general modifiers’, the remaining methods use the full amount of information in the database), a priori information (‘no rubble/field stone buildings’ in methods 2, 4 and 6) or they use a different key to weight the modifier information (methods 3 and 5 use the ‘standard key’ described in case A in Table 1 and methods 4 and 6 use a building type specific key corresponding to case B of Table 1). The a priori information that no rubble/field stone buildings exist is derived from the following assumption: even if the construction material corresponds to this building type, buildings would not behave in the bad way proposed by EMS98 (vulnerability A) because this building type inherently represents non-engineered very poor buildings in rural and weakly industrialized regions of Europe. It has to be mentioned, that the Swiss engineering community disagrees on this issue.

Vulnerability Reliability
To demonstrate the result variability, we show the mean vulnerability of all eleven city districts for which inventory data has been assessed in Table 4.

Table 4 Mean vulnerability of city districts 1 to 11 for all six methods

method	A	B	C	D	E	F
1	12	36	52	0	0	0
2	0	48	52	0	0	0
3	7	17	38	37	1	0
4	3	14	45	37	1	0
5	14	36	47	3	0	0
6	3	47	47	3	0	0

We note that the two methods which only use 'base vulnerability' (methods 1 and 2) have no vulnerability D buildings. This means, that vulnerability D is only reached, when the quality modifiers indicate a 'good condition' value. The two methods using the 'standard key' to convert modifier into plus and minus vulnerability produce a very high ratio of vulnerability D buildings – with respect to the high amount of URM buildings (84%) in the overall inventory the amount of 37% vulnerability D buildings seems very high. The effect of the a priori information of 'no rubble/field stone buildings' in methods 2, 4 and 6 leads to a significant decrease of vulnerability A buildings. As a general trend and as can be expected, the use of the general modifiers leads to a smearing of the vulnerability classes.
Apart from these general observations we can have a closer look at results from two out of the eleven city districts assessed. We choose city districts no. 1 and 10. The first being part of the historical center of the city and the second one is a typical residential city district in the town. We show the results in Figure 3:

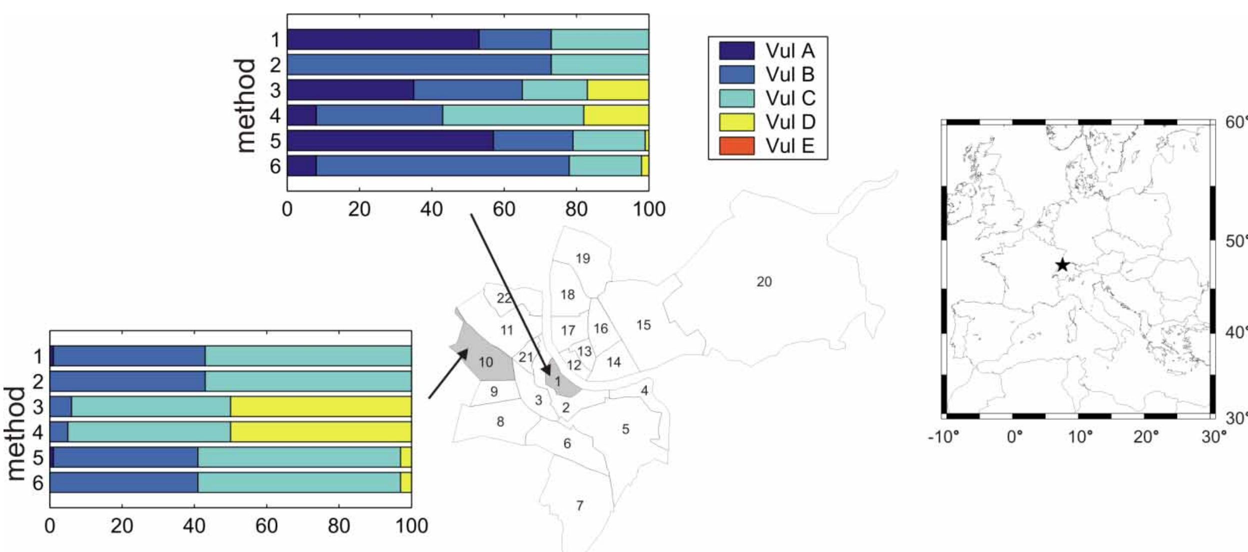

Figure 3 City of Basel with the city districts. Map showing position within Europe with a star. Bar plots for city districts 1 and 10 give the percentage of buildings in vulnerability A to E for all 6 different methods described in Table 3

First we note that the result variability between the six methods is higher for city district 1 (historical center) than for 10 (typical residential district). This can be explained by the large amount of vulnerability A buildings in city district 1 (> 10%) so that the a priori information 'no rubble/field stone buildings' has a big impact on the results of methods 2, 4 and 6. In city district 10, where almost no rubble/field stone buildings were identified, the a priori information plays no role. Secondly we have to discuss the observation, that in city district 10 methods 1 & 5 and 2 & 6 lead to very similar results. This means, that the use of the modifier data with the building type specific key has only limited effect on the result (adds few vulnerability D buildings to the inventory) and therefore future vulnerability assessment studies could omit this data. Although true in the case presented it must be kept in mind that the result is very sensitive to the character of the key used to associate plus and minus vulnerability steps. This can clearly be seen when comparing the results of methods 3 & 5 and 4 & 6, respectively which only differ in this key used.

Effect on Earthquake Scenarios

In our last step we demonstrate the influence of the inventory using a straightforward method to calculate earthquake scenarios previously presented by Fäh [5]. We calculated scenarios using intensity IX as a regional input throughout the whole city and then added the effect of local soil conditions (maximum effect plus and minus one intensity degree based on a qualitative microzonation map). We used vulnerability curves derived from EMS98 [2] to calculate damage. Three different damage values were calculated for the six scenarios using the six inventories presented above:

1. overall damage which was calculated using a central damage factor for every damage grade
2. the percentage of buildings in damage grade 4 (i. e. heavily damaged buildings)
3. and the same for damage grade 5 (i. e. collapsed buildings)

In Figure 4 the result variability (vertical bars span the maximum/minimum range in the results of the six scenarios) in the different city districts and for the three damage measures is given:

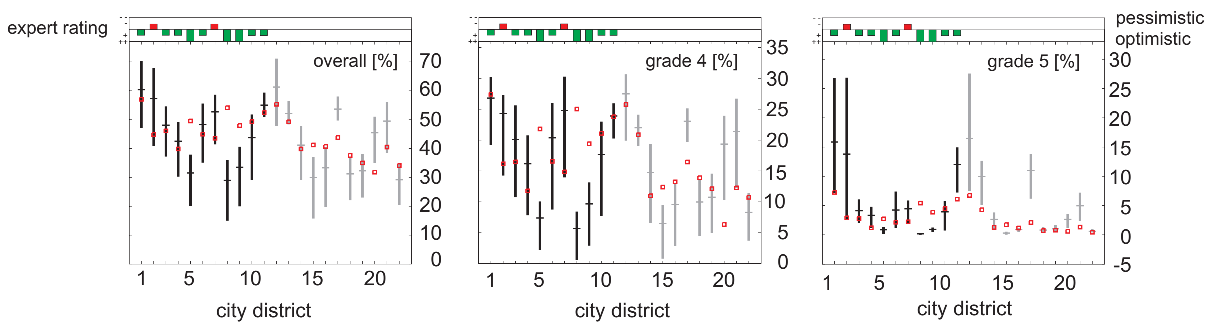

Figure 4 Result variability in the scenario calculations. Extreme value difference (vertical bar) together with mean value (black horizontal line) and values from ultra fast scenario (red square) from [5] are given. On top, expert rating shows the influence of the building inspector on the result variability (see text for explanation).

Result variability is high in all three damage measures (note the different scales). Differences between the extremes in the overall damage vary strongly between 8 and 27%. Mean deviation is 18%. For grade 4 damage the resulting deviation between the individual scenarios lies between 5 and 17% with a mean deviation of 11%. For grade 5 damage, the large result variability is restricted to city districts 1, 2 and 12, the historical part of the city. The large amount of rubble/field stone buildings and the use of the a priori information 'no rubble/field stone buildings' completely changes the pattern of the grade 5 damage results: whereas in the worst case scenario, up to 28% of the buildings are expected to collapse only 3 to 7% will suffer the highest damage grade in the best case. With respect to planning for catastrophe, this difference is key.

In addition to the result variability, Figure 4 allows a comparison to the results of Fäh [5] (called here 'scenario no. 7') in which a very quick method to assess building information was used (fast visual inspection of different regions of the city, study of city planning maps and use of historical archives). Compare the red markers (scenario no. 7) with the small horizontal lines of city districts 1 to 11 for which we have assessed direct observational data (the inventory for the remaining city districts has been inferred

from the others). The results of scenario no. 7 are more uniform most of all for the grade 5 measure. They lie within the range of results spanned by the other six scenarios but often are more optimistic (indicating a lower damage level). This trend is most accentuated in the grade 5 results. Only in city districts 5, 8 and 9 are the results of scenario 7 more pessimistic. Here the qualitative indications of 'expert rating' can be used for an explanation. This rating could be derived when looking at the type of misinterpretations the individual experts did with respect to reference dataset assessed by Lang [4]. An expert whose results tended to be in higher vulnerability classes (towards F) than indicated by the reference was given an 'optimistic' tag and in the opposite case the expert was given a 'pessimistic' tag. The difference of the results in city districts 5, 8 and 9 are directly linked to a 'double optimistic' rating of the corresponding building inspector. It is therefore highly possible that the deviations of the scenario results 1 to 6 from no. 7 are due to a bias coming from the building inspector. When looking at the expert's rating section on top of the bar plots, we notice a clear link between the expert's rating and the position of the vertical bars below: optimistic ratings are linked to lower damages and pessimistic ratings to the opposite.
This observation stresses the importance of pre-studies in inventory assessments including calibration of the results coming from different experts.

Discussion
We present a fast and cost efficient method to assess a building inventory in the city of Basel with which we assess 10% of the overall building stock. Comparison to reference data gave good correspondence of the 'year of construction' and the 'number of floors' parameter but revealed specific problems in the identification of the construction type. Main problems occurred when identifying the floor type in URM buildings, when distinguishing rubble/field stone building type from URM and distinguishing the RC/masonry mix type construction from its end members RC wall and URM with RC floor building type.
Six different concepts were used to derive building vulnerability from the inventory data – all basing on the definitions of EMS98. We noted the highest result variability in city districts where the amount of rubble/field stone buildings was above 10%. To demonstrate the effect of varying inventory data on earthquake scenarios, these six inventories were used in an intensity IX earthquake scenario for the city of Basel. Result variability was high, accentuating the influence of the method to derive vulnerability from the building type information and the expert's personal opinion when assessing building data. This highlighted the importance of pre-studies in inventory assessments. They help avoiding errors due to mix-up of difficult building types and may reduce the influence of personal opinion of the building inspectors. For areas of low seismicity, where observed damage from earthquakes is missing, there is no way to calibrate structural information with any observed damage data. Using different methods to derive building vulnerability from structural information is highly recommended.

UNCERTAINTY IN DETERMINISTIC EARTHQUAKE SCENARIOS

Introduction
In this part of the work we present results coming from a systematic investigation of uncertainty in earthquake scenario calculation. We combine logic tree and Monte Carlo methods to account for parameter uncertainties and influence of systematic changes of parameters. Our calculation procedure is a straightforward method to calculate deterministic earthquake scenarios using intensities as ground motion measure in order to allow the use of macroseismic data and scales, which are still of importance in regions of low to moderate seismicity.
We use an approach to describe the earthquake focus as a line source based on Smith [6]. Together with the attenuation relation derived from macroseismic investigations SED [7] we calculated regional intensity. By using a qualitative microzonation of the city of Basel by Fäh [8] we can account for local amplification and de-amplification effects. Seven different versions of the map exist which can be used in the scenario calculations. The maps differ in expert opinions on the weighting scheme of the geological

input layers. The qualitative microzonation information has to be converted to incremental intensity by using a maximum range of intensity variation due to the local site conditions. Summing up regional and incremental intensity leads to our local intensity map used as ground motion input into the damage calculation procedure. The second input required to derive damage is the information about the buildings in the area of interest. Here we use the results of the fast screening assessment described in the first part of this article. Our damage calculation procedure bases on the definitions of the European Macroseismic Scale 1998 (EMS98) by Grünthal (Ed.) [2]. EMS98 describes the effects of ground motion on people, smaller and larger objects and on buildings. We use the last part – the description of building damages – for our purposes. The textbox below gives an example of the damage descriptions in EMS98 for a heavily damaging earthquake (intensity VIII):

VIII. Heavily damaging

Many buildings of vulnerability class A suffer damage of grade 4; a few of grade 5.

Many buildings of vulnerability class B suffer damage of grade 3; a few of grade 4.

Many buildings of vulnerability class C suffer damage of grade 2; a few of grade 3.

A few buildings of vulnerability class D sustain damage of grade 2.

By using terms as ‘few’, ‘many’ and ‘most’ for the quantity of buildings in a certain damage degree, EMS98 contains means to account for uncertainty in the damage calculation procedure. We modeled the terms ‘few’, ‘many’ and ‘most’ as uniformly distributed random variables within the ranges [0 15], [15 55] and [55 100] percent, respectively. Hence letting the parameters be defined in every Monte Carlo calculation run, we can randomly change the shape of the damage curves for every run.

Figure 5 describes the single elements of the earthquake scenarios and the concept of parameter variation within the calculation runs.

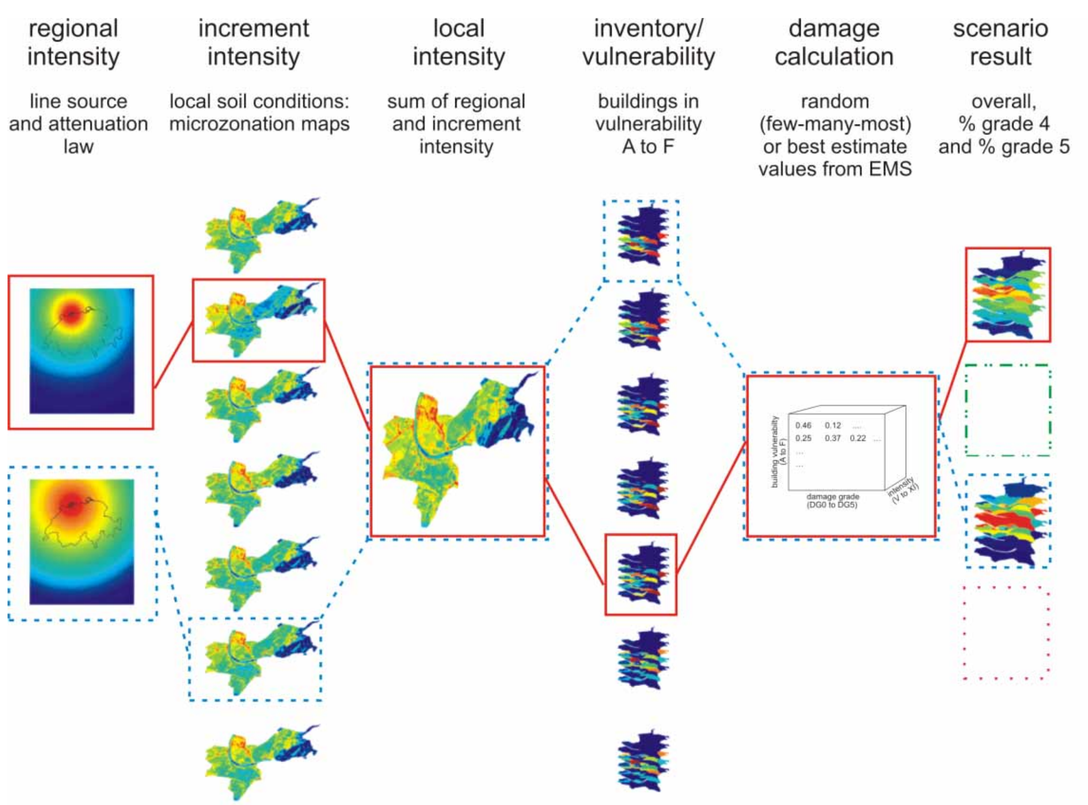

Figure 5 Calculation scheme of earthquake scenarios and approach for parameter variation

The different lines in Figure 5 symbolize possible combinations of parameters for individual calculation runs. We combined random variation of parameters (MC) with best estimate (BE) selections of others which were systematically changed throughout a calculation (logic tree type modification for example going through all possible microzonation maps). A result group consists of K sets (K possible values of a systematically changed parameter) of a number of M Monte Carlo runs (we used M=500 random parameter selections). Result interpretation can focus on the impact of the systematically changed values in the N sets or on internal variation of results within the M Monte Carlo runs due to randomly changed parameters.

Table 5 lists the parameters together with the random variable definition for the selected scenario earthquake (the historical intensity IX earthquake in the city of Basel 1356). Parameters were derived from SED [7] and Meghraoui [9]. Note that BE values for the parameters for which random selection is possible always correspond to the expected values in the normally distributed random variables.

Table 5 Parameters used in the different elements of the scenario approach. N: normal distribution with expected value and variance, U: uniform distribution between given boundaries

scenario element	parameter(s)	parameter definition
regional intensity	epicenter latitude	epilat~N(47.47,0.1)
	epicenter longitude	epilon~N(7.60,0.01)
	fault magnitude	faultmag~N(6.9,0.25)
	focal depth	depth~N(12,5)
	fault azimuth	faultaz~N(22.25,5)
	attenuation relation	BE: CH [7]
increment intensity	maximum intensity variation	X~N(1,0.25)
	expert opinion for microzonation map	seven different approaches
inventory/vulnerability	vulnerability maps (for vul. A to F)	seven different approaches
damage calculation	vulnerability curves composed EMS98 definitions with parameters: 'few', 'many' and 'most'	few~U(0,15)
		many~U(15,55)
		most~U(55,100)
		BE: (mean of 100 sets of 100'000 different random variables)
scenario result – overall	central damage factor	BE: CDF_def=[0 5 20 55 90 100]

We used normal distribution of the parameters of source and intensity variation and uniform distribution for the terms 'few', 'many' and 'most'.

Results

Our first sample results focus on the influence of the parameters used to define regional intensity and increment intensity (see Table 5). We let the parameters be randomly varied one by one and set the others to their best estimate values. In the last set we randomly varied all regional intensity and increment intensity parameters. The results are given in terms of 'overall damage' (using a central damage factor to summarize damages in the different damage degrees), 'grade 4' (percentage of buildings in damage degree 4) and 'grade 5' (percentage of buildings in damage degree 5) damage. We show the results for three different geographical areas: all city districts (mean results), city district no. 1 in the historical part of the city and city district no. 10 which is a typical residential area (Figure 3). The box plots display the variation of the results of the K scenarios in every Monte Carlo scenario set (box represents interquartile range [IQR] between q_{25} and q_{75}), whiskers give the upper ($UL = q_{25} - 1.5*IQR$) and lower limit ($LL = q_{75} - 1.5*IQR$), possible outliers are marked with red crosses. The dashed green line marks the mean results for the scenario using all best estimate parameters. Figure 6 has the results:

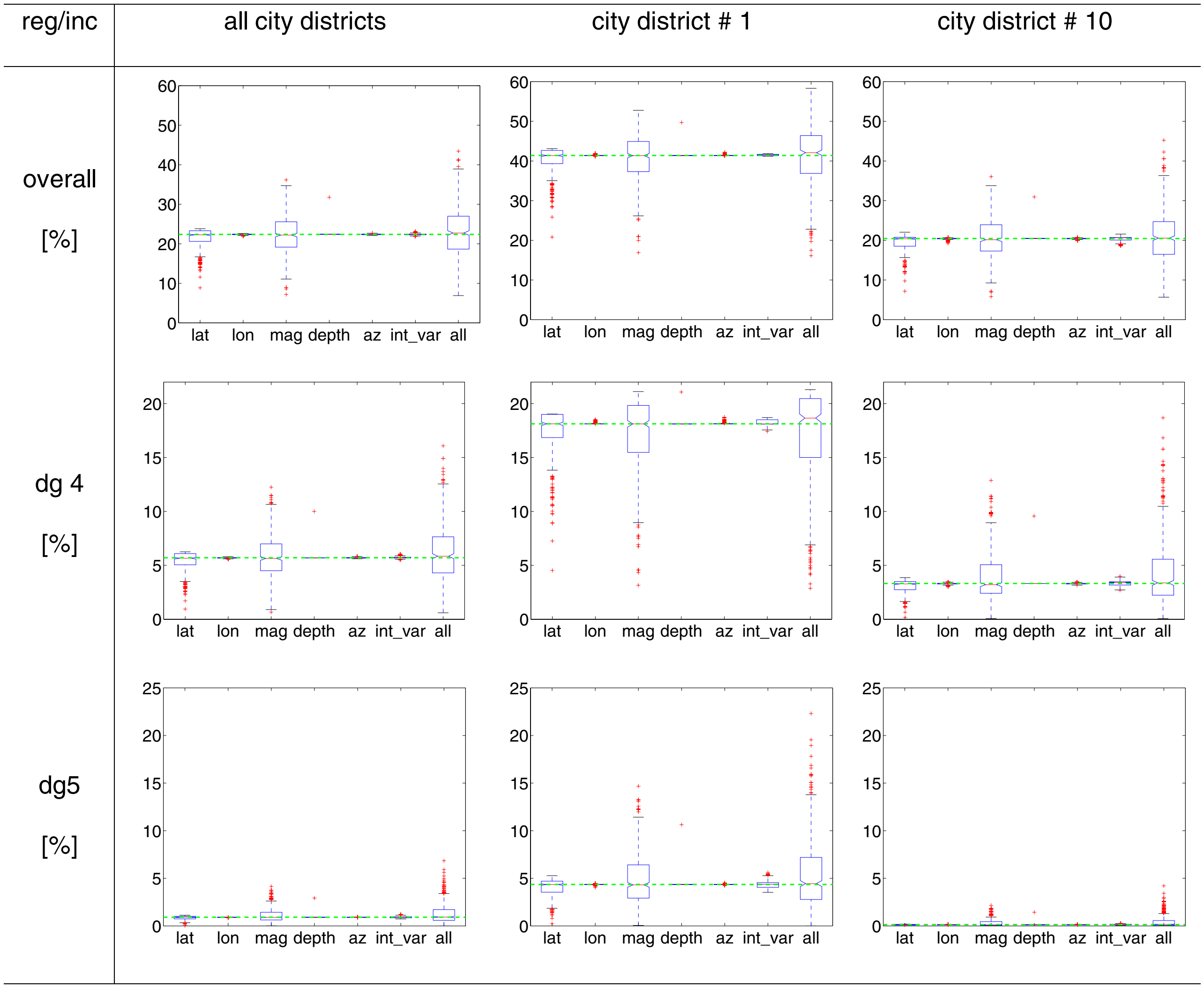

Figure 6 Scenario results: influence of the parameter variability of the regional and incremental intensity

Damage axis definition is the same for all figures in horizontal lines. Therefore we can clearly recognize the different levels of damage (dashed green line) in the city mean and in the two sample city districts (this can be explained by the different inventory in the corresponding areas). The median value is not affected by the parameter variation and is the same in all scenario sets because all random distributions of the parameters are symmetrical around their expected (best estimate) values. When focusing on the result variability within the different result sets (size of box and whisker extent), we see that the two parameters 'epicenter latitude' (first box plot from the left) and 'magnitude' (result set 'mag') have the strongest impact on the overall result variability (result set 'all'). The different plots reveal approximately the same results for all regions and all damage measures the only difference is the asymmetry of the results towards higher or lower damage values.

In a second scenario group we used our randomized damage calculation procedure and went through the seven different microzonation layers available. Results are given in Figure 7 for the overall damage measure. The box plots for the individual scenario sets for the results of 'all city districts' are all aligned horizontally along the dashed line indicating best estimate results. This means, that the choice of the expert opinion in microzonation plays a minor role on the mean result. This had to be expected for the average results of the whole city because the individual microzonation maps do only differ in expert opinions on the weighting of seven geological input layers. The results of city districts no. 10 and no. 11, both typical residential areas, show a higher variability between the individual sets of scenario runs. The reason for this is the geological setting in the corresponding area, which is – depending on the individual expert's opinion – favorable or not in case of an earthquake. The internal spread (size of box and extent of whiskers) of the results in the scenario sets is about the same for all microzonation maps chosen and for all regions.

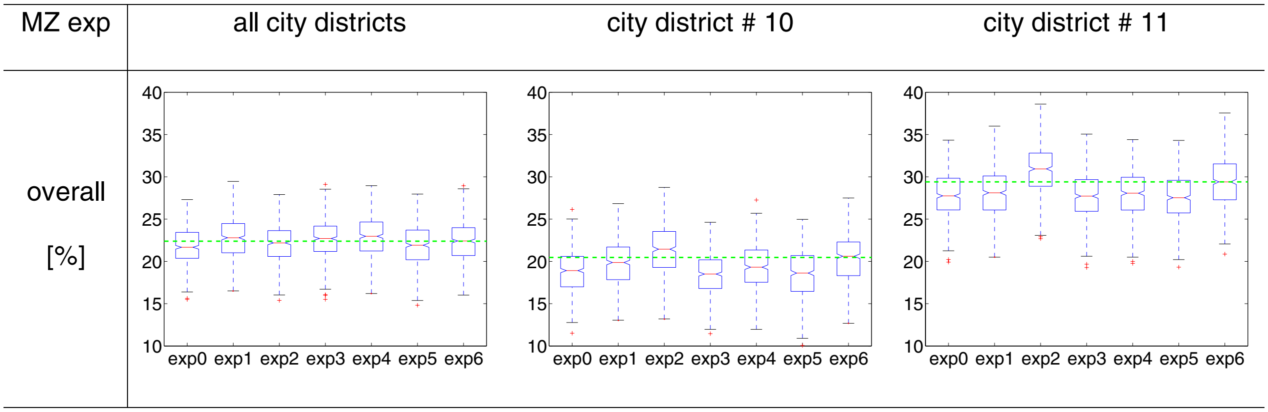

Figure 7 Results variability coming from systematic change of microzonation expert opinion and use of random damage calculation

Our last example shows the systematic change of the inventory layer and again the use of the random damage calculation procedure. Here we see a clear increase of the result variability between the individual scenario sets (mid line in single box plots). This effect is most accentuated for city district no. 1 due to the reasons already discussed in the first part of this work. It is to notify that our best estimate inventory (inv 5) which has been selected based on methodological reasons, gives the highest damages in the scenario calculations. As in the example before, the use of a randomized damage calculation procedure leads to a scatter of the results within the individual scenario sets (size of box and extent of whiskers). The scatter is most accentuated in city district no. 1 where we have a lot of highly vulnerable buildings and it seems to depend on the type of inventory used (it tends to be small for inventories 3 and 4 and is larger in the other cases).

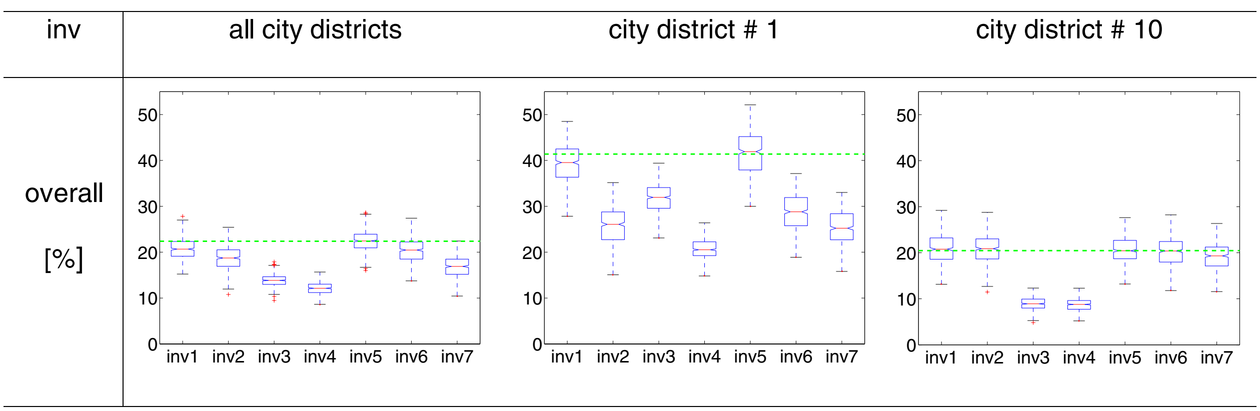

Figure 8 Result variability coming from systematic change of inventory layer and use of random damage calculation

Discussion

The three sample results of uncertainty in regional and incremental intensity parameters, in microzonation and in inventory reveal different aspects of uncertainties in scenario calculations. In the variation of the scenarios source and local intensity parameters the total variability of the results was clearly dominated by the two parameters 'epicenter latitude' and by its 'magnitude'. The remaining parameters played a minor role and therefore uncertainty in longitude, azimuth, and intensity variation can be neglected in the scenario case presented. Note that the magnitude uncertainty will play a dominant role in all scenarios but that other parameters could be of higher importance, when changing the set of best estimate parameters. This still needs further analysis. The two remaining results: the effect of the microzonation layer and the inventory can be compared to each other. By comparing the level of result change between the single sets of scenarios it becomes obvious, that the influence of microzonation uncertainty is much lower. The difference in the median values of the single result sets does not exceed the internal result variability in the single sets (due to the randomized damage calculation procedure). Even in regions, where the individual microzonation maps differ from each other (city district 10 and 11) the median values of the overall damage only change weakly. The result variability due to the randomized damage calculation procedure is almost constant in all result sets. Inventory results on the other hand show high result variability between the individual sets. Boxes of the box plots do not overlap and the selection of the 'correct' inventory layer is key. Apart from that it can be observed that the choice of the inventory influences the internal result variability due to the randomized approach in damage calculation (size of boxes differ depending on inventory chosen).

CONCLUSIONS

We have investigated uncertainties in scenario calculations. In the first part of the work the focus lied on data assessment of inventory information and the uncertainties when translating structural information into vulnerability data in cases where no observations from past earthquakes help to calibrate the vulnerability functions. We found, that in cases where low-cost methods are the only feasible way of assessing inventory data – which is often the case – fast screening type analysis leads to a significant amount of uncertainty. Bias has to be expected due to expert's opinion in data assessment as well. Thorough expert trainings and pre-studies could help to reduce these uncertainties but increase the costs of the data assessment. In our approach to convert structural information into vulnerability of buildings we followed the definitions of the European Macroseismic Scale 1998 and accounted for methodological uncertainties by using six slightly different approaches. Our sample scenario calculations demonstrate the strong impact of the inventory on the scenario results and should increase awareness of hidden uncertainties in scenario results when using inventory data of unknown precision – which is in many studies a common case.

In the second part of this article we show sample results of a systematic investigation of the uncertainties within earthquake scenario parameters. The combination of Monte Carlo procedures and logic tree type variation of key parameters gives an impression of the result variability due to uncertainty in input parameters. The total result variability of the source parameters is clearly dominated by the magnitude – a very obvious result but nevertheless an important one when thinking at problems finding a single magnitude value for an event in the past. When studying earthquake catalogues, a spread of half a magnitude for one event is quite common. A second finding is again the high impact of the choice of the inventory layer. For the scenarios presented, the intensity variation due to local soil conditions (microzonation) is much lower. This tells us that microzonation can be well defined and is a mean for efficient risk mitigation. Further investigation has to be made with other best estimate parameter sets and on combined effects of different parameters.

REFERENCES

[1] FEMA "FEMA-154, Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook." Federal Emergency Management Agency and Applied Technology Council (ATC-21), 1988.

[2] Grünthal G. (Ed.) "European Macroseismic Scale 1998", Cahiers du Centre Européen de Géodynamique et de Séismologie, Vol. 15, Conseil de L'Europe, Luxembourg, 1998.

[3] SIA. "Norm SIA 160: Belastungsannahmen, Inbetriebnahme und Überwachung der Bauten", Schweizerischer Ingenieur- und Architektenverein, Zürich (in German).

[4] Lang K. "Seismic Vulnerability of existing Buildings." Dissertation ETH No. 14446, 2002.

[5] Fäh D, Kind F, Lang K and Giardini D. "Earthquake scenarios for the city of Basel." Soil Dyn. Eq. Eng. 2001; 21: 405 – 13.

[6] Smith W. D. "A Procedure for Modelling Near-Field Earthquake Intensities." Bull. New Zealand Nat. Soc. for Eq. Eng. 1995; 28: 218 – 23.

[7] SED. "ECOS - Earthquake Catalogue of Switzerland." ECOS Report to PEGASOS, Version 31.3. 2002, Swiss Seismological Service, Zurich. (available on the internet: http://histserver.ethz.ch/publications_e.html

[8] Fäh D, Rüttener E, Noack T, Kruspan P. „Microzonation of the City of Basel." Journal of Seismology 1997; 1: 87 – 102.

[9] Meghraoui M, Delouis B, Ferry M, Giardini D, Huggenberger P, Spottke I, Granet M. "Active Normal Faulting in the Upper Rhine Graben and Paleoseismic Identification of the 1356 Basel Earthquake." Science 2001; 293: 2070 – 73.