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SEISMIC VULNERABILITY FUNCTIONS FOR SWITZERLAND

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SUMMARY

For the assessment of potential seismic losses insurance and reinsurance companies work with deterministic event scenarios coupling the seismic hazard with the vulnerability of the built environment and the exposed values. Whereas, however, a lot has been done in recent times to improve the assessment of the seismic hazard in Switzerland, vulnerability functions are still largely based on observations and expert opinions from other countries with the additional problem of applicability. The goal of this study is therefore the definition of vulnerability functions based on characteristic features of the buildings in Switzerland.
Historical macroseismic observations are the best currently available source of damage information for Switzerland and the historical catalogue is naturally expressed in intensities. Therefore, this study is based on the vulnerability descriptions of the European Macroseismic Scale (EMS). Typical construction types in Switzerland are defined and compared to the standard construction types of the EMS. So far, the study is limited to the most important construction types in Switzerland: Unreinforced masonry and reinforced concrete wall structures. Using a scoring system in the style of ATC-21 the differences to the vulnerabilities of the standard construction types are expressed quantitatively resulting in a correction of the vulnerability functions of the EMS for the respective construction types.

1. INTRODUCTION

Switzerland is a country with rather moderate seismicity on the world scale. But although no damaging earthquake has occurred in recent times, it is well known from historical records that major destructing earthquakes have occurred and are therefore likely to occur again. On the other hand the exposed values in Switzerland are very high and hence the corresponding seismic risk cannot be neglected. For insurance and reinsurance companies it is important to quantify the risk associated with earthquakes in order to predict the expected losses. This is usually done using deterministic event scenarios coupling the spatial distribution of the seismic impact parameters with the vulnerability of the built environment and the exposed values.

In the last few years a lot has been done to improve the assessment of the seismic hazard, the latest hazard map for Switzerland being recently released in 2004 [Giardini et al., 2004]. Comparatively little, however, has been done on the assessment of the vulnerability of the existing buildings in Switzerland. A few studies exist, yet these focus on a particular town, such as Basel [Fäh et al., 2001], [Lang, 2002], [Steimen et al., 2004] or Aigle [Brennet et al., 2001]. A vulnerability study comprising the whole of Switzerland does not exist.

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Hence, for risk scenarios, the vulnerability functions used are often based on observed vulnerability functions or expert opinions from other countries usually with higher seismic hazard. The building types in those countries are often very different from the ones in Switzerland and thus the applicability of those vulnerability functions to the building stock in Switzerland remains questionable. In addition, the distribution of the various building types having different vulnerabilities in Switzerland is not known. In fact, a project with the aim to define vulnerability functions for typical Swiss building types was recently launched by the Swiss Federal Institute of Technology in Lausanne and the Swiss federal office for the environment (risk prevention division), but so far only a first definition of structural types in Switzerland without reference to vulnerability and distribution has been performed [Belmouden and Lestuzzi, 2005].

The goal of the study presented in this paper is the derivation of vulnerability functions for typical building types in Switzerland for the purpose of the seismic risk assessment. Since the assessment of the seismic hazard is largely based on the historical record of past earthquakes [Swiss Seismological Service, 2002], which are qualitative descriptions of the impact of past earthquakes, the proposed vulnerability functions are based on Intensity as seismic impact parameter. The damage descriptions of the European Macroseismic Scale [Grünthal, 1998] are used to derive the vulnerability functions.

2. VULNERABILITY FUNCTIONS ACCORDING TO EMS

The definition of the intensities in the European Macroseismic Scale (EMS) [Grünthal, 1998] is largely based on building damage. The EMS distinguishes five damage grades ranging from negligible damage to destruction. Each damage grade is defined by typical damage to the structural and non-structural elements (Table 1).

Table 1: Damage grades according to EMS

Damage grade	Definition
1	Negligible to slight damage (no structural damage, slight non-structural damage)
2	Moderate damage (slight structural damage, moderate non-structural damage)
3	Substantial to heavy damage (moderate structural damage, heavy non-structural damage)
4	Very heavy damage (heavy structural damage, very heavy non-structural damage)
5	Destruction (very heavy structural damage)

In contrast to other vulnerability studies which define vulnerability functions for specific structural types, the EMS differentiates six vulnerability classes (classes A to F, with decreasing vulnerability). For each intensity degree $I \geq V$, the expected damage is described for each vulnerability class. The definition of the intensity degrees only quotes the two highest damage grades assuming that in an idealised case the damage grades for buildings of one vulnerability class are normally distributed. I.e. if for one intensity degree it is specified that few buildings of one vulnerability class suffer damage of grade 4 and many of grade 3, one should assume that many buildings of that vulnerability class will also suffer damage of grade 2, few of grade 1 and a few will remain undamaged. In that way, for each vulnerability class the expected damage at each intensity degree can be deduced. This procedure was already applied for the risk scenario study for the city of Basel [Fäh et al., 2001].

The number of buildings of one vulnerability class suffering a certain damage grade is defined by the terms few, many and most. The interpretation of these terms as percentages will strongly influence the resulting vulnerability functions. Table 2 shows the ranges of possible interpretations according to EMS. The bold figures indicate proposed mean values, also used for other vulnerability studies for the city of Basel [Fäh et al., 2001], [Steimen et al., 2004].

Table 2: Quantitative interpretation of the terms few, many, most

few	1 – **8** – 18
many	12 – **35** – 58
most	52 – **75** – 100

Figure 1 shows an example of the resulting distribution of damage grades for vulnerability class B. Shown is the cumulative distribution. The lines correspond to a non linear interpolation between the points at the integer intensity values. The continuous lines represent mean values for the frequency distribution as indicated in bold in Table 2, the dashed lines represent rather pessimistic and optimistic interpretations corresponding to the upper and lower bounds of the ranges in Table 2. The difference in the damage distributions due to different interpretations of the terms few, many and most thus becomes evident.

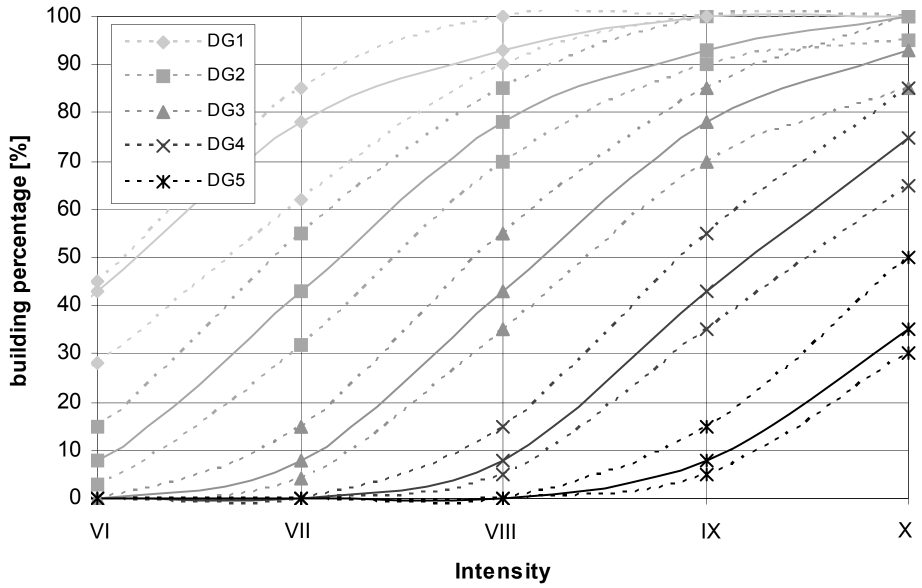


Figure 1: Distribution of damage grades for vulnerability class B

3. STRUCTURAL BUILDING TYPES IN SWITZERLAND

Table 3 shows the relevant structural building types in Switzerland. They are based on the classification of structural types of the EMS [Grünthal, 1998]. The structural types adobe masonry, reinforced masonry and reinforced concrete structures with high level of earthquake resistant design which are also listed in the EMS are not considered as theses structural types are rather unusual for Switzerland. Instead the two mixed structural types: Unreinforced masonry / reinforced concrete and unreinforced masonry / timber are introduced, which constitute a considerable part of the building stock in Switzerland.

Furthermore, the different types of unreinforced masonry (rubble stone, field stone, simple stone, massive stone, brick etc.) are not distinguished. The reason being that in Switzerland the different types of stones are often combined in one wall making an assignment difficult. Besides, tests have repeatedly shown that the quality of the mortar is predominant in determining the quality of the masonry. Even rubble stone masonry can develop high strength if bonded by cement mortar. The mortar used in Switzerland, however, has changed over the last 100 years. Whereas at the beginning of the 20th century lime mortar was the most common mortar used, at the middle of that century only cement mortar was used. Therefore, for the vulnerability, the construction period is also considered (cf. section 4.4).

In their study, Belmouden and Lestuzzi [2005] pointed out that another important structural type in Switzerland are the reinforced concrete precast structures and suggested an additional class. Further research is needed to justify this separate class.

Table 3: Relevant structural building types in Switzerland

Structural type	Abbreviation	Description
Unreinforced masonry with flexible floor systems	URM + flexible floors	Unreinforced masonry with cut or uncut natural or manufactured stone units with flexible floors systems (e.g. timber)
	URM + steel	Perimeter walls of unreinforced masonry, floor girders and columns of steel (flexible floor system)
Unreinforced masonry with reinforced concrete floors	URM + RC floors	Unreinforced masonry with manufactured stone units (concrete, brick) with reinforced concrete floors (rigid floor system)
Mixed structure of unreinforced masonry and reinforced concrete	URM-RC mixed	Walls of reinforced concrete and unreinforced masonry with reinforced concrete floors
Reinforced concrete frames	RC frame	Moment resisting reinforced concrete frames, constructed prior to 1989 or in zones 1 and 2*
Reinforced concrete frames with earthquake resistant design	RC frame ERD	Moment resisting reinforced concrete frames, constructed after 1989 and in zone 3
Reinforced concrete walls	RC walls	Reinforced concrete walls, constructed prior to 1989 or in zones 1 and 2
Reinforced concrete walls with earthquake resistant design	RC walls ERD	Reinforced concrete walls, constructed after 1989 and in zone 3
Steel structures	Steel	Moment resisting steel frames or braced steel frames
Timber structures	Timber	
Mixed structure of unreinforced masonry and timber	URM-Timber mixed	Ground floor with unreinforced masonry walls and upper floors with timber walls
		Timber frame with masonry fillings

4. ASSIGNMENT OF VULNERABILITY CLASSES TO STRUCTURAL TYPES

In the European Macroseismic Scale (EMS) for each structural type a most likely vulnerability class with probable and less probable ranges is assigned. It is assumed that the most likely vulnerability class corresponds to a standard structural type. In order to characterise these standard structural types comparisons with other vulnerability studies [Coburn and Spence, 2002] [GNDT, 1993] [ATC-13] were made. From this it was concluded that the standard structural types tend to be rather regular in plan and elevation with medium height and building condition.

In order to determine to what extent typical Swiss building types correspond to these standard structural types of the EMS the following procedure was applied:

- Determination of factors influencing the vulnerability
- Quantification of the influence
- Pilot project evaluating buildings in a typical small town in Switzerland
- Assignment of EMS vulnerability classes to typical structural building types in Switzerland

* These zones correspond to the seismic hazard zones of the Swiss Standard [SIA 261].

4.1 Factors influencing the vulnerability

Discrepancies from the standard structural type will lead to a variation in the vulnerability. Numerous experiences from past earthquakes have demonstrated important factors which influence the vulnerability of a building. Table 4 gives a summary of the important factors, indicating their influence on the vulnerability of a building and the characteristics of the standard structural type with respect to these factors.

Table 4: Factors influencing the vulnerability

Factor	Influence	Standard structural type
Building height	Increase of vulnerability with building height	4-7 stories URM: 1-3 stories
Condition (initial quality of material and construction, maintenance, previous damage and aging)	Bad condition increases vulnerability whereas very good condition reduces the vulnerability	In Switzerland generally better than average
Soft story	Increase vulnerability	Without soft story
Masonry infill	Increase vulnerability	Without masonry infill
Short columns	Increase vulnerability	Without short columns
Pounding of adjacent buildings	Increase vulnerability	No danger of pounding
Torsion	Increase vulnerability	No torsional effects
Irregularities in plan	Increase vulnerability	compact
Irregularities in elevation	Increase vulnerability	Regular
Heavy cladding	Increase vulnerability	No heavy cladding
Terraced house	Decrease in vulnerability	Detached house
Earthquake resistant design	Decrease in vulnerability	Already considered in structural type

Of course, the list in Table 4 is not complete. Other factors exist which have an important influence on the vulnerability of a building. However, they are more difficult to assess and hence are neglected in this study.

4.2 Quantification of factors influencing the vulnerability

In order to quantify the factors which influence the vulnerability a scoring system is introduced based on the scoring system of the Applied Technology Council [ATC-21] which was already adapted to Switzerland [Basler & Hofmann, 1992]. The factors take values between –2 and +1/2. Positive values indicate a smaller vulnerability compared to the standard structural type whereas negative values indicate an increased vulnerability. Since the influence of each factor depends on the type of structure the values differ for the various types of structure.

In comparison with [ATC-21] the two structural types “steel frame with masonry infill” and “reinforced concrete with masonry infill” were omitted, instead the factor “masonry infill” was introduced. The value of the factor was chosen based on the differences in the basic structural hazard score according to [ATC-21].

As already mentioned before, the structural type RC-URM mixed is very important in Switzerland. A separate column was therefore introduced. The values correspond to mean values of the factors for URM and RC walls.

Table 5: Quantification of factors influencing the vulnerability

			steel structure			reinforced concrete			
Factors influencing vulnerability	timber	URM	moment resisting frame	with RC walls	braced frame	frame	precast	structural walls	RC-URM mixed
light	-1/2	-1/2	-1/2	-1/2	-1/2	-1/2	-1/2	-1/2	-1/2
low	-	-	+1/2	+1/2	+1/2	+1/2	-	+1/2	+1/2
bad condition	-1/2	-1/2	-1/2	-1/2	-1/2	-1/2	-1/2	-1/2	-1/2
very good condition	+1/2	+1/2	+1/2	+1/2	+1/2	+1/2	+1/2	+1/2	+1/2
soft story	-1	-1	-2	-2	-2	-2	-1	-2	-1 1/2
masonry infill	-	-	-1/2	-	-	-1	-	-	-
short column	-	-	-	-	-	-1	-1	-1	-1
pounding of adjacent buildings	-	-	-1/2	-1/2	-1/2	-1/2	-1/2	-	-
torsion	-1	-1	-1	-1	-1	-1	-1	-1	-1
irregularities in plan	-1/2	-1	-1/2	-1/2	-1/2	-1/2	-1	-1/2	-3/4
irregularities in elevation	-1/2	-1	-1/2	-1/2	-1/2	-1	-1	-1/2	-3/4
heavy cladding	-	-	-2	-	-	-1	-1	-	-
terraced house	-	+1/2	-	-	-	-	-	+1/2	+1/2

The sum of the factors in one column (i.e. for one type of structure) gives a quantitative value of the discrepancy of a building from the standard structural type. In the EMS reinforced concrete structures with earthquake resistant design are considered one vulnerability class less vulnerable than reinforced concrete structures without earthquake resistant design. [ATC-21] rates the factor "earthquake resistant design" with a value +2. It is therefore assumed in this study that a sum of the factors of ±2 is equivalent to a shift in the vulnerability of one vulnerability class. For values of the sum of the factors between 0 and ±2 it is interpolated between the respective vulnerability classes.

4.3 Pilot project

In order to determine to what extent typical Swiss building types correspond to the standard structural types of the EMS a building survey was carried out in a typical small town in Switzerland. Around 70 buildings were screened in a pilot project which focused on buildings of reinforced concrete and unreinforced masonry. Each building was allocated to a structural type according to Table 3 and possible discrepancies from the standard structural type were assessed using the factors of Table 5. For a sum of the factors equal to 0, the most likely vulnerability class according to the EMS is assumed and for a sum of the factors different form 0 the vulnerability was shifted towards another vulnerability class (cf. 4.2). The resulting vulnerability classes are shown in Table 6. It can be seen that the vulnerability classes of the four structural types considered correspond rather well to the most likely vulnerability classes. This is mainly due to the assumptions that the buildings in Switzerland are in general in a very good condition and hence some irregularities, which are often present, are compensated. Only the structural type URM-RC mixed is more vulnerable than the materials unreinforced masonry walls and reinforced concrete walls would suggest. This is primarily due to the high irregularities of these buildings which are also confirmed by the study in Basel [Lang, 2002]. In fact, the vulnerability of the structural type URM-RC mixed was even evaluated to be higher due to an often rather unfavourable layout of the walls in plan. This factor, however, could not be assessed in this study.

Table 6: Vulnerability of sample of buildings in Switzerland

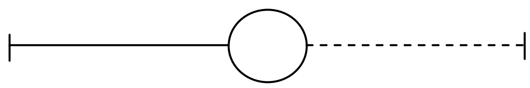
Structural system	Mean factor	Percentage of buildings per vulnerability class				
		A	B	C	D	E
URM + flexible floors	0.08	6	93	1	0	0
URM + RC floors	-0.22	0	22	72	6	0
URM-RC mixed	-0.93	0	50	50	0	0
RC walls	0.13	0	13	87	0	0

The pilot project identified also certain difficulties when assessing buildings by a street survey. Whereas the factors influencing the vulnerability can be assigned with a good confidence, the structural type itself is often difficult to determine without the respective drawings:

- Especially unreinforced masonry walls, reinforced concrete walls and mixed structures with unreinforced masonry walls and reinforced concrete walls are very difficult to differentiate as the structure is usually hidden behind plaster.
- Also it is not possible to distinguish unreinforced masonry structures with timber floors from those with reinforced concrete floors. On the basis of experience it was therefore assumed that buildings constructed before 1950 have flexible floors whereas those constructed later have reinforced concrete floors. But as the construction date is usually not known, some uncertainty remains.

4.4 Vulnerability functions for Swiss building structural types

Table 7 shows the proposal for the differentiation of building structural types into vulnerability classes for Switzerland. Values printed in bold are proposed mean values. Because the number of buildings screened during the pilot project is rather limited, the vulnerability studies in Aigle [Brennet et al. 2001] and Basel [Steimen et al. 2004], [Lang, 2002] were also considered. For the types of structures other than unreinforced masonry and reinforced concrete wall structures, the differentiation of the EMS is adopted, using the quantification shown in Figure 2.



qualitative terms	probable	most likely	less probable
range of percentage	15-30%	60-100%	5-10%

Figure 2: Quantification of the terms "most likely", "probable" and "less probable"

As already proposed in chapter 3 the different types of masonry for URM structures with flexible floors are not distinguished. However, it is proposed to vary the vulnerability depending on the period of construction thus taking into account the development of the mortar from pure lime mortar at the beginning of the 20th century to pure cement mortar by the middle of the century. Also for the period before 1920 the stone units are very diverse with rubble stone, simple stone and manufactured brick units often used in the same wall whereas later the brick units became predominant.

The proposed vulnerability for the structural type URM-RC mixed is higher than derived from the pilot project. This is due to the experiences from the Basel study [Lang, 2002] which has shown a very high vulnerability of this building type. For the structural type URM-timber mixed no vulnerability studies exist and therefore the proposed vulnerability corresponds to a mean vulnerability of timber structures and URM structures with flexible floors. This, however, has to be verified.

Table 7: Differentiation of building structural types into vulnerability classes

Type of structure	Vulnerability class					
	A	B	C	D	E	F
URM + flexible floors < 1920	15-**20**-30	60-**80**-100				
URM + flexible floors 1920 - 1950	5-**10**	60-**85**-100	**5**-10			
URM + flexible floors > 1950	5-**7.5**-10	60-**85**-100	5-**7.5**-10			
URM + RC floors		15-**20**-30	60-**75**-100	**5**-10		
URM-RC mixed	10-**15**-20	30-**50**-70	20-**35**-50			
RC walls		**5**-10	60-**75**-100	15-**20**-30		
RC walls ERD			**5**-10	60-**75**-100	15-**20**-30	
RC frame	**5**-10	15-**20**-30	60-**70**-100	**5**-10		
RC frame ERD		**5**-10	15-**20**-30	60-**70**-100	**5**-10	
URM-timber mixed		15-**20**-30	**60**-100	15-**20**-30		
timber		**5**-10	15-**20**-30	**60**-100	**15**-30	
steel			**5**-10	15-**20**-30	**60**-100	**15**-30

5. FINANCIAL LOSS

The step further into the financial loss from the structural damage is not an element of EMS. We focused in this study on the structural damage and give only an indication for the financial losses. The core part is the interpretation of the damage description for possible actual damages and their respective repair and replacement costs. These will vary between structural types and have to be estimated individually. But in general the costs for the repairs as a percentage of the total value of the object are larger than the percentage for structural damage.

A first approach towards financial loss is an estimation of the range of loss values for the damage grades. Damage grade one in the EMS is described as no structural damage but slight non-structural damage. Although such damages are minor in terms of structural stability, the costs for repairs can go up to 10% of the building value. Damage grade two is described slight structural and moderate non-structural damage. To assess the extent of repairs needed, some detailed inspections and tests might be required. Injections in cracks and similar work might be necessary. Facade elements and plaster might need partial or total replacement. So the costs could go up to about 20% of the building value.

Damage grade three is the most difficult to assess financially, as the visual inspection resulting in this classification can stem from mostly superficial non-structural damage up to significant structural damage. So the range of financial loss can reach up to a 100% loss, but could also represent only 20% of the value. Damage grade four and five then can be expected to be total losses financially.

The ranges for the financial losses for the damage degrees have to be associated with probability distributions. To do so, statistics on repair costs for various types of construction and forms of damage are needed. It has to be kept in mind that the resulting vulnerability functions are only meaningful for a large number of structures considered as an ensemble. This lies in the character of Intensities as a descriptive classification of earthquake effects in a limited area.

6. CONCLUSIONS

In this paper, vulnerability functions for typical Swiss building types based on the European Macroseismic Scale are presented. Since vulnerability studies in Switzerland only exist for a few selected places such as Basel and Aigle a methodology is proposed for the assessment of the vulnerability of buildings using a scoring system in analogy to ATC-21. This methodology aims at the assessment of structural building types rather than individual buildings. A pilot project demonstrates the application of the methodology to a typical small town in Switzerland. However, the number of buildings assessed so far is very limited, and hence the proposed vulnerability functions only have an indicative character. In order to verify the proposed vulnerabilities the methodology has to be applied to more buildings comprising all typical locations (urban, suburban, rural in the different parts of Switzerland) and use (residential, commercial, industrial).

The conclusions that can be drawn for the vulnerability functions so far are:

- The vulnerability classes of the structural types URM + flexible floors, URM + RC floors and RC walls correspond rather well to the most likely vulnerability classes according to the EMS.
- The structural type URM-RC mixed is more vulnerable than the materials unreinforced masonry walls and reinforced concrete walls would suggest due to the irregularities which characterise these buildings in Switzerland.

A very important aspect for risk scenarios for Switzerland is the distribution of the various structural types in Switzerland. As no database exist from which this information can be drawn the methodology can be used to establish databases for typical locations.

Finally, for the use of these vulnerability functions for risk scenarios and loss estimations, the damage grades of the European Macroseismic Scale have to be associated to some financial loss which can be done by considering the qualitative description of the damage grades and possible upgrading strategies.

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