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EARTHQUAKE VULNERABILITY AND LOSS ESTIMATION MODELS FOR BUILDINGS IN SWITZERLAND – OVERVIEW AND COMPARISON

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SUMMARY

This paper aims at presenting and comparing different models used to assess earthquake vulnerability and associated risk for buildings in Switzerland.

For assessing **earthquake vulnerability and risk on a regional scale** with aggregated data and results, two very different models are being used in Switzerland. The first model, named EMS model in this paper, is defining the hazard in terms of EMS98 intensities and uses vulnerability functions based on this parameter [1]. The second model, named HAZUS® model, is an adaptation for Switzerland of the US software HAZUS®99 SR2 distributed by the Federal Emergency Management Agency (FEMA) [2]. This model is defining the hazard in terms of spectral acceleration, velocity and displacement and uses fragility functions mainly based on spectral displacement.

A demonstration project in the canton (state) of Nidwalden with a dataset of 10'500 buildings allowed a first comparison between the two models. The calculated risk premium for buildings varies from a factor 1 for the Hazus® model to 3.1 for the EMS model. This comparison shows a reasonable agreement knowing all the uncertainties affecting earthquake risk calculations. Using the Hazus® model alternatively with aggregated and georeferenced input data allowed to analyze the influence of the data aggregation on building risk premiums. For this study, the aggregation of information on a communal (census tract) level does not substantially affect the average building risk premium of the whole study area with an average difference of only 6%. On a communal level, the difference can be significantly higher with variations up to 60%.

For assessing **earthquake vulnerability and risk for building portfolios** with object specific results and limited resources (typically half a day per building), two models are currently used in Switzerland. The first model is a direct application of FEMA 154 with a few minor adaptations for Switzerland [3]. FEMA 154 allows a vulnerability assessment based on a checklist of structural and soil parameters. From a final score, the building earthquake vulnerability is ranked ok, unclear or not ok. The second model, named RS1 in this paper, has been initially developed at the Swiss Federal Institute of Technology Zürich and is now further developed by Risk&Safety AG [4]. The procedure is very similar to FEMA 154 for vulnerability assessment but it also allows for a systematic prioritization based on a risk index.

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The 2 models have been used for a set of 224 federal buildings as part of the federal buildings seismic safety inventory [5]. A comparison of vulnerability indexes for both methods shows a good correlation with more than 75% of agreement. For this study, 50% of the buildings are ranked not ok or unclear after FEMA 154 whereas 46% of the buildings are ranked as not ok after RS1. Furthermore, RS1 shows that 85% of the risk index total sum comes from only 30% of the building set, which shows that the risk index is essential for a clear prioritization of buildings for detailed safety evaluation studies and retrofit planning. This concept is a clear advantage of the RS1 method over FEMA 154.

INTRODUCTION

On a worldwide scale, the earthquake hazard in Switzerland is moderate to low depending on the region. An earthquake of magnitude 5 is expected on average once every 10 years, and a magnitude 6 earthquake once every 100 years. The strongest historically known earthquake to hit Switzerland devastated the city of Basel in 1356 and had an estimated magnitude of 6.9.

The high financial loss potential due to buildings vulnerability makes earthquake risk the most important natural related risk in Switzerland. Approximately 90% of existing buildings in Switzerland have not been designed with seismic requirements or have been designed for obsolete seismic requirements and could therefore be vulnerable. The reinsurance industry expects damages to buildings worth approximately 7 billion Swiss francs for a magnitude 5.5 to 6 earthquake and 40 billion francs for a magnitude 6 to 6.5.

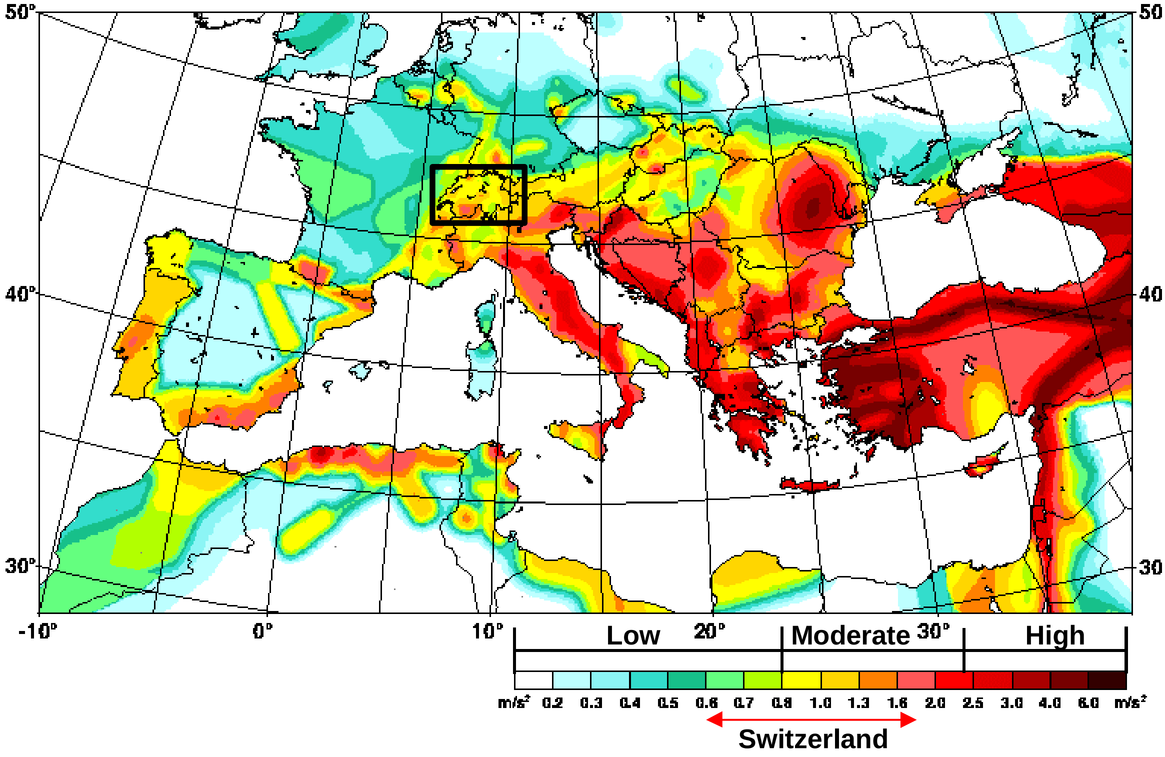

Figure 1: Earthquake hazard in central Europe and around the Mediterranean basin. Source : ESC-SESAME project [6]

According to the scale and objectives of a study, several tools for assessing buildings vulnerability and risk are available. This paper is giving an overview of the different tools used in Switzerland with a focus on some interesting findings derived from application projects.

Three groups of tools can be considered. At a regional scale, the tools are aimed at estimating financial and human potential losses with aggregated input information. The main users are insurers, reinsurers and intervention planners. At a building portfolio scale, the tools are aimed at assessing the seismic vulnerability of building sets with object specific results. The objective is a prioritization for in depth analysis and seismic retrofit. At an individual building scale, the tools are aimed at accurately assessing the vulnerability and risk of individual existing buildings. Acceptable risk and cost/benefit decision criteria for the pertinence of a retrofit options are central to this third level of tools.

This paper focuses on the first two scale levels (regional and building portfolio), for which methods and results for several projects are available for comparison purposes. For the third scale level (individual building), new tools are actually under development [7] or at the stage of preliminary application [8] in Switzerland making it too early for a valuable comparison analysis.

PART 1: ASSESSING EARTHQUAKE VULNERABILITY AND RISK ON A REGIONAL LEVEL

The EMS model

The EMS model is defining the hazard and the vulnerability functions in terms of EMS98 intensity. The vulnerability function can be unique such as in [9], or buildings can be assigned to a vulnerability class with an associated vulnerability function such as in [10], [11] or [12] (figure 2). In the EMS98 systematic, 5 different building classes named A to F and 5 different damage grades named 1 to 5 are defined [1]. The vulnerability function for each class is not explicitly given and the user must set numerical parameters on the basis of semi-qualitative indications such as "for intensity VII, few buildings of class C suffer damage of grade 3".

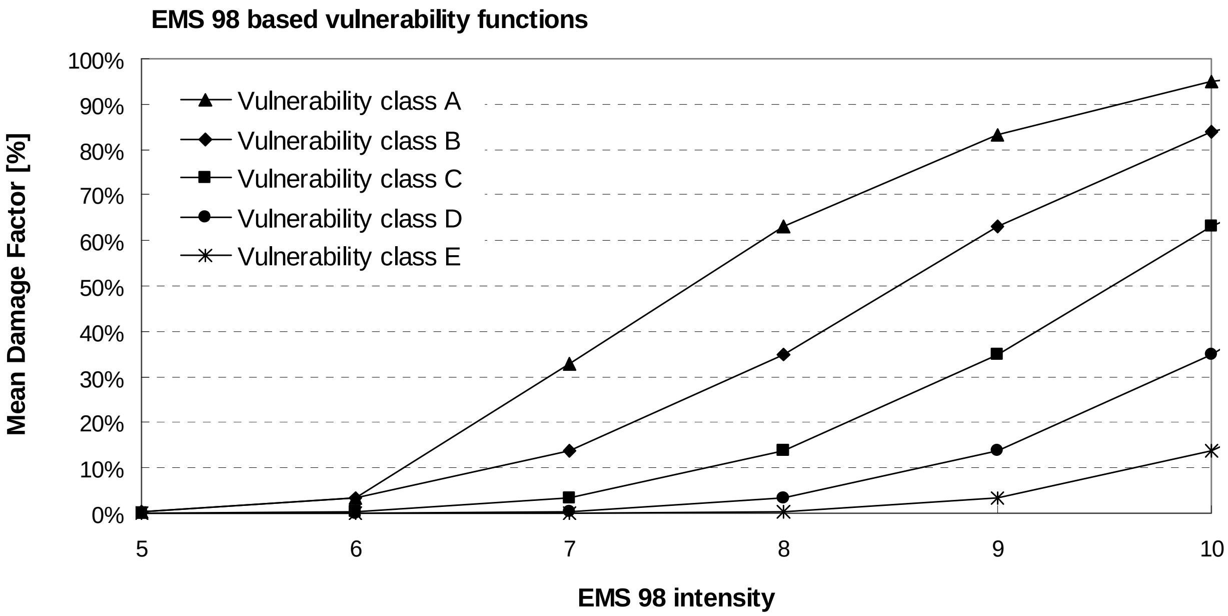

Figure 1: Example of vulnerability functions with EMS 98 intensity as hazard parameter.

The effects of local geology and induced effects is expressed globally through an increase or decrease of the average intensity given in hazard studies for a very dense soil (NEHRP class C).

Different building risk premium studies performed with this model in Switzerland are summarized in table 1 and figure 3.

Study region	**Importance**	**Ref.**	**Seismic zone / PGA$_{475}$ / Microzoning**	**Vulnerability classes**	**Risk premium [o/oo per year]**
Basel city (BS)	166’000 inhabitants 18'500 buildings	[9]	3a / 0.13 g / no	unique	0.33 o/oo
Sion (VS)	28’000 inhabitants 4’200 buildings	[9]	3b / 0.16 g / no	unique	0.45 o/oo
Stans (NW)	6’700 inhabitants 1’400 buildings	[10]	2 / 0.10 g / yes	5 classes	0.80 o/oo (0.80 o/oo – 1.40 o/oo)
Aigle (VD)	7'500 inhabitants 1'500 buildings	[11]	3a / 0.13 g / yes	5 classes	0.19 o/oo (0.10 o/oo – 0.30 o/oo)

Table 1: Summary of earthquake building risk premium according to the EMS model in Switzerland

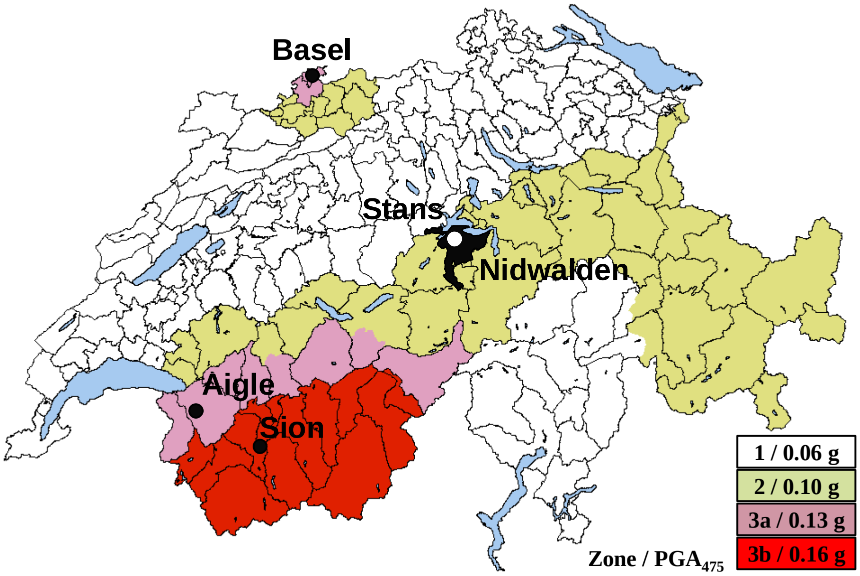

Figure 3: seismic zones and location of earthquake building risk premium studies in Switzerland

Table 1 shows a wide dispersion of results between the 4 studies presented. Taking extreme cases, the risk premium varies over a factor of 1 to 10. Taking central values, the risk premium varies over a factor of 1 to 4. After discussion with the author of the study in Aigle [11], it comes out that the risk premiums calculated for this study have an unconservative bias and will have to be updated.

A comparison of 2 earthquake vulnerability studies for the city of Basel, one without microzoning and only one vulnerability class [9] and the other one with microzoning and 4 different vulnerability classes [12], shows the influence of the detailing of the study on the calculated losses. For a scenario with an earthquake of intensity IX, the first study gives an overall loss percentage of 28%, whereas the second one calculates loss percentages varying from 31% to 56% depending on the city district. For the second study, the non pondered average of loss percentage over the city districts is 44%.

The HAZUS® model

The HAZUS® model, is an adaptation for Switzerland of the US software HAZUS®99 SR2 distributed by the Federal Emergency Management Agency (FEMA) [2]. The model is defining the hazard in terms of spectral acceleration, velocity and displacement. Its building vulnerability functions are based on spectral displacement (figure 4). In Hazus®, there are 36 buildings types, 3 possible design levels (low, medium, high) and 3 code bias (inferior, normal, superior) describing the code compliance.

The effect of local geology on hazard parameters is expressed through multiplication factors depending on the NEHRP soil class These factors are editable and can be adapted to local microzoning studies. Furthermore, susceptibility maps for liquefaction and landslides can be introduced.

The Hazus® model is adapted to modern seismology and earthquake engineering, but lacks calibration data in Switzerland and Europe in general. For this model, research work is needed, mainly in order to calibrate its vulnerability functions which have been developed according to the US built environment.

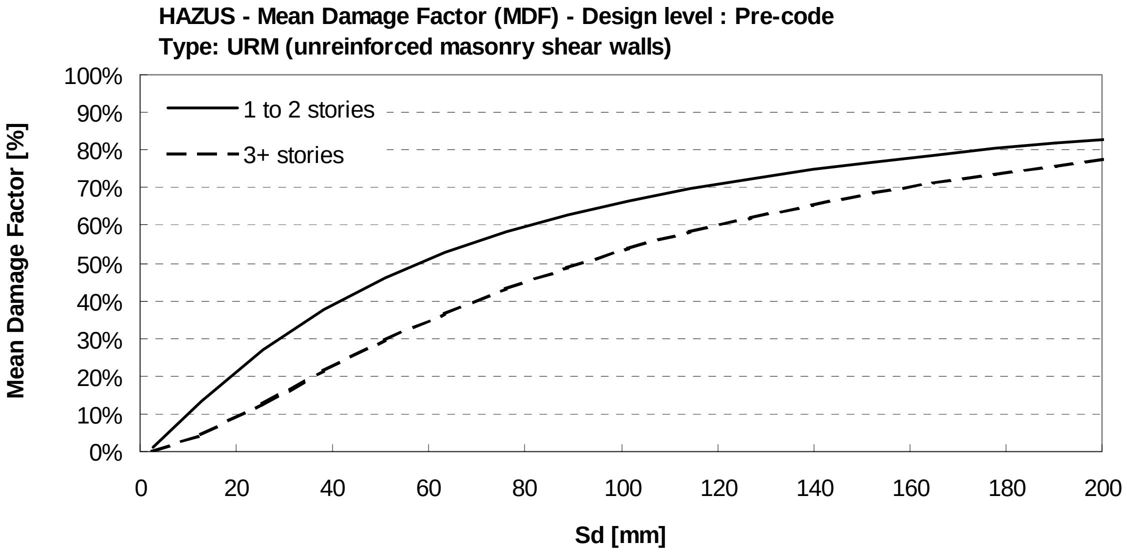

Figure 4: Hazus® structural vulnerability functions for pre-code unreinforced masonry buildings

The first demonstration project with Hazus® for Switzerland has been performed by the authors [13] for the canton (state) of Nidwalden in central Switzerland (figure 3). This small canton has 11 communes (census tract), 37’000 inhabitants, 10'500 buildings (insurance value 8.6 bil. SFr.) and an area of 276 km^2. It is located in the Prealps in seismic zone 2, close to some well known historical earthquakes epicenters.

The database of buildings of the state property insurance has been adapted for Hazus® (figure 5). The low design level with an inferior code bias has been systematically selected to reflect the general non compliance of buildings with seismic provisions of building codes. The following 2 options have been tested for hazard and building information input data in order to evaluate their influence on earthquake building risk premium calculations (Table 2).

- all buildings were represented as objects with real coordinates and an individually associated soil class and hazard parameter.
- all the information was aggregated at each commune centroid with only one soil class and one hazard value valid for the whole commune.

For this study, the hazard has been defined using the hazard maps of the Swiss Seismological Service for rock conditions and a NEHRP soil class map and the associated amplification factors (figure 5).

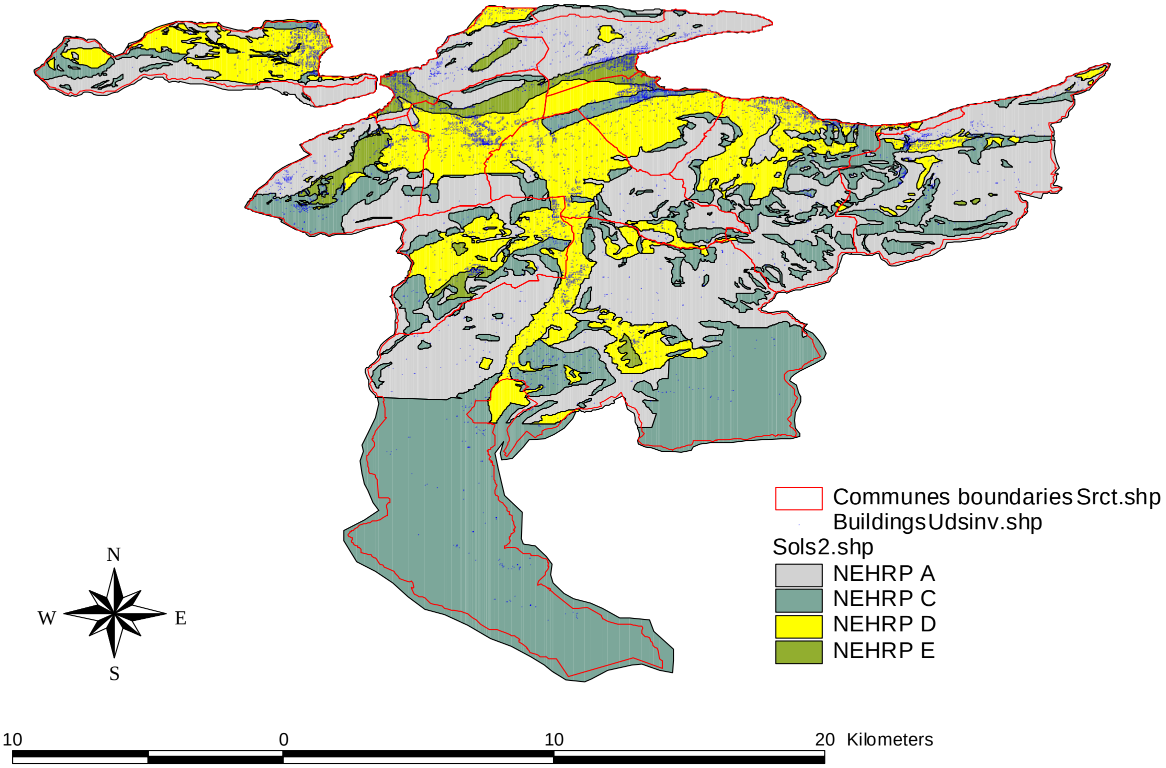

Figure 5: NEHRP soil class map, commune boundaries and georeferenced buildings in Nidwalden

Commune (census tract)	**Aggregated data**	**Georeferenced data**	**Difference (ref. georef.)**
1501 Beckenried	0.41 o/oo	0.36 o/oo	12%
1502 Buochs	0.41 o/oo	0.52 o/oo	-26%
1503 Dallenwill	0.39 o/oo	0.34 o/oo	12%
1504 Emmetten	0.23 o/oo	0.24 o/oo	-3%
1505 Ennetbürgen	0.95 o/oo	0.68 o/oo	29%
1506 Ennetmoos	0.38 o/oo	0.36 o/oo	6%
1507 Hergiswil	0.40 o/oo	0.48 o/oo	-20%
1508 Oberdorf	0.40 o/oo	0.41 o/oo	-1%
1509 Stans	0.44 o/oo	0.70 o/oo	-58%
1510 Stansstad	0.95 o/oo	0.85 o/oo	11%
1511 Wolfenschiessen	0.36 o/oo	0.27 o/oo	24%
Average	**0.51 o/oo**	**0.55 o/oo**	**-6%**

Table 2: Computed risk premium in the canton of Nidwalden with the Hazus® adaptation for Switzerland

Comparison study between the EMS model and the Hazus® model in the canton of Nidwalden

The Hazus® demonstration project in the canton (state) of Nidwalden and a prior study [11] that investigated the building earthquake risk premium for the commune of Stans using the EMS model allowed a first comparison between the 2 models. Table 3 summarizes the different results obtained.

Model	**Risk premium**
Hazus® model, aggregated input data	0.44 o/oo
Hazus® model, georeferenced data	0.70 o/oo
EMS model, average vulnerability	0.80 o/oo
EMS model, pessimistic vulnerability	1.39 o/oo

Table 3: calculated risk premium for buildings for the commune of Stans in the canton of Nidwalden

This comparison shows a reasonable agreement knowing all the uncertainties affecting the calculation of earthquake building risk premiums. Further comparison studies are necessary to gain a better perspective.

Comments

The EMS model and the Hazus® model both have their advantages and disadvantages. To this date, no model can claim a better accuracy than the other for assessing earthquake risk in Switzerland. Working with both models is a good way to gain a better perspective on the results uncertainty. The EMS model is certainly better calibrated with data from actual events, but is far less able to incorporate the newest results in seismology and earthquake engineering such as hazard maps and vulnerability functions based on spectral parameters.

The Hazus® model has the advantage of being a complete user friendly software with capabilities that go beyond building risk premium calculations. The analysis of lifelines and critical infrastructure vulnerability is also possible, also many related parameters must be adapted for Switzerland. On the other hand, the EMS model still requires from the user the development of its own numerical software tool.

PART II ASSESSING EARTHQUAKE VULNERABILITY AND RISK FOR BUILDING PORTFOLIOS

FEMA 154 model

FEMA 154 [3] allows a vulnerability assessment based on a checklist with structural, soil and age parameters (figure 6). Each parameter is assigned a score. The sum of all scores determines if the building earthquake vulnerability is ranked ok, unclear or not ok.

RS1 model

The second model, named RS1 in this paper, has been initially developed at the Swiss Federal Institute of Technology Zürich and is now further developed by Risk&Safety AG [4]. The procedure is very similar to FEMA 154 for vulnerability assessment but it also allows for a systematic prioritization based on a risk index which is the multiplication of the vulnerability index times a potential damage index (figure 6).

	RS1		FEMA 154	
Parameter	**Index**	**Rule**	**Index**	**Rule**
Importance	AIF	1 (normal), to 5 (vital)	***Not considered***	
Occupancy	ADP	0.1 x (Avg. occupancy)		
Value	ADS	0.1 x (Value in mio. SFr.)		
DAMAGE POT.	**AZPS**	**AIF x (ADP + ADS)**		
Structural system	WW	1 to 4	STARTING SCORE	2.5 to 4.5 * * depending on type of structure and material
Building material	WD	1 to 3 3 + n/2, URM 3 + n, URM, flexible decks		
Height	n	# of stories ab. ground	Z1	-1.0 to 1.0 *
Building condition	-	***Not considered***	Z2	-0.5 (bad condition) 0 (normal condition)
Bracing system in elevation	WA	0 (continuous) 2 (non continuous) 5 (soft story)	Z3 or Z6	-1.0 to -2.0 (soft story) * -0.5 to -1.0 (irregular) * 0 (otherwise)
Bracing system in plan	WG	0 (adequate) 2 (inadequate) 5 (missing)	Z6	-1.0 to -1.5 (inadequate) * 0 (otherwise)
Unreinforced masonry infill	-	***Not considered***	Z4	-1.0 (if present) * 0 (otherwise)
Pounding	-	***Not considered***	Z5	-0.5 to -1.0 (pounding likely) * 0 (otherwise)
Concept in plan	WK	0 (regular) 1 (irregular or long)	Z7	-0.5 to -1.0 (irregular or long) * 0 (otherwise)
Facade elements	-	***Not considered***	Z9	0.0 to -1.0 (heavy elements) * 0 (otherwise)
Foundation type	WF	0 (continuous) 1 (isolated)	Z11	0.0 to -0.5 (isolated) * 0 (otherwise)
Seismic zone and period	WEP	1 (zone 1 - post 89) to 30 (zone 3b - pre 70)	Z12	0.0 (pre 89) 0.5 (post 89)
Soil	WB	1 (good) 2 (average) 4 (bad)	Z10	-1.0 (bad) -0.5 (average) 0 (good)
VULNERABILITY	**WZ**	**WEP x WB x (1+WG+ WA+WW+WK+WD+WF)**	**FINAL SCORE**	**STARTING SCORE + SUM (Zi)**
		WZ >= 65 : not ok **WZ < 65 : ok**		**Criteria: >= 2.0 = ok; 0.0 to 1.5 (unclear); < 0.0 (not ok)**
RISK	**RZPS**	**AZPS x WZ**	***Not considered***	
		RZPS > 500 high risk **RZPS < 500 lower risk**		

Figure 6: comparison of FEMA 154 and RS1 models

Comparison study between the FEMA 154 model and the RS1 model

The 2 models have been used for a set of 224 buildings from the federal buildings seismic safety inventory [5]. A comparison of the vulnerability index for both methods shows a good correlation with 76% of agreement (table 4). For this study, 50% of the buildings have a vulnerability that is not ok or unclear after FEMA 154 whereas 46% of the buildings are ranked as not ok after RS1.

	RS1: OK			**RS1: NOT OK**		
FEMA 154	**Number**	**[%] of RS1 ok**	**[%] of total**	**Number**	**[%] RS1 not ok**	**[%] total**
OK	90	74%	40%	22	21%	10%
UNCERTAIN	29	24%	13%	53	51%	24%
NOT OK	2	2%	1%	28	27%	12%

Table 4: Comparison of vulnerability indexes after FEMA 154 and RS1 for 224 federal buildings. Shaded areas represent cases of contradictory results between the two methods.

An analysis of the discrepant cases led to the following observations:

- Buildings build before 1970 in zones of highest seismicity (zone 3a and 3b) and showing no to few negative characteristics have a tendency to be rated ok with FEMA 154 and not ok with RS1. This is due to the fact that RS1 uses a penalty factor associated with the seismic zone and FEMA 154 does not. In RS1 the penalty factor describes the fact that there is a higher likelihood of unsatisfactory seismic behavior in zones of higher seismicity than in zones of lower seismicity.

- Wood and prefabricated buildings built before 1970 in seismic zone 2 and showing no to few negative characteristics have a tendency to be rated ok with FEMA 154 and not ok with RS1.

- Unreinforced masonry buildings built before 1970 and showing no negative characteristic other than an irregularity in plan have a tendency to be ranked uncertain with FEMA 154 and ok with RS1.

Inventory of seismic safety of federal buildings with the RS1 model

The seismic safety inventory of federal buildings has started with a first set of 284 buildings, all located in seismic zones 2, 3a and 3b. The RS1 model has been selected for the first phase of this seismic inventory. A priority list of buildings with 4 priority categories has been established on the basis of the risk index coupled with the vulnerability index (table 5).

Priority	**Vulnerability index criteria**	**Risk index criteria**	**Number of buildings**	**Percentage of the buildings**	**Percentage of the total risk index**
1	Not ok	High risk	48	17%	75%
2	Ok	High risk	22	8%	13%
3	Not ok	Lower risk	83	29%	6%
4	Ok	Lower risk	131	46%	6%

Table 5: Prioritization concept for the first phase of the federal buildings seismic safety inventory

After going through the priority list with the authorities responsible for the building portfolio, 94 buildings have been selected for a more refined analysis with an adaptation of FEMA 310 for Switzerland. These 94 buildings represent 29% of the total number of buildings but 85% of the total sum of the risk index.

When analyzing table 4 one sees that 131 buildings are ranked as not ok after the vulnerability index. From these 131 buildings, only 71 have been selected in the final list of buildings to be further evaluated. Furthermore, 13 buildings with a low vulnerability index have been selected based on their high risk potential. This clearly shows that a priority list after a vulnerability index or a priority list after a risk index will be substantially different.

CONCLUDING REMARKS

Part I: Assessing earthquake vulnerability and risk on a regional level

The EMS model has been used for many years in Switzerland. It has benefited from calibration data in Europe, but is relying on a hazard parameter that tends to be abandoned in modern hazard assessment and which is not suitable for modern earthquake engineering.

The Hazus® model is adapted to modern seismology and earthquake engineering, but lacks calibration data in Switzerland and Europe in general. For this model, research work is needed, mainly in order to calibrate its vulnerability functions which have been developed for the US built environment.

Working with both models is a good way to gain a better perspective on the results uncertainty.

Part II: Assessing earthquake vulnerability and risk for building portfolios

The FEMA 154 model and the RS1 model show a good agreement as far as vulnerability assessment is concerned. The RS1 model has the clear advantage of offering a prioritization of buildings based on a risk index, which is more logical than a prioritization based on a vulnerability index.

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