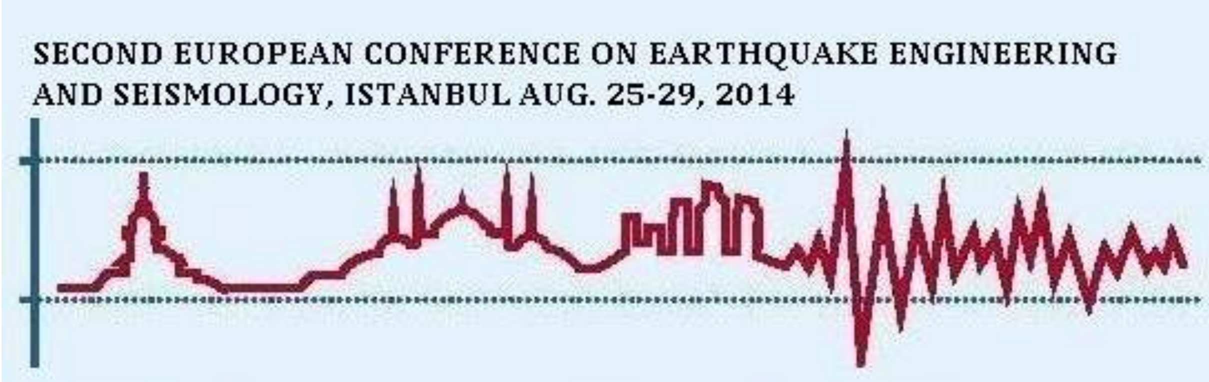

SEISMIC CONSERVATION STRATEGIES FOR CULTURAL HERITAGE BUILDINGS IN SWITZERLAND

Thomas Wenk[1] and Katrin Beyer[2]

ABSTRACT

Cultural heritage buildings were typically built without considering seismic action and are therefore potentially susceptible to earthquake damage. The performance states and protection objectives developed for ordinary buildings are not directly applicable since they do not address the cultural importance of the heritage buildings. This paper proposes a seismic conservation strategy for cultural heritage buildings in Switzerland, which is a country of low to moderate seismicity. Based on the performance states for cultural heritage buildings that were developed within the Pereptuate project, a matrix of performance states has been developed in function of the importance category of the cultural property, the conservation strategy chosen and the return periods for seismic events to be considered. It is proposed that the performance states and return periods for ordinary buildings should define the lowest performance that is acceptable for cultural heritage buildings since these performance states were derived considering minimum protection requirements for people. For cultural heritage buildings such low performance states are acceptable if the importance of the heritage is minor and/or if a conservation strategy is chosen, which is based on the documentation of the status quo with the objective of reconstruction after a seismic event rather than retrofit and improvement of the seismic performance.

INTRODUCTION

Cultural heritage buildings were typically built long before the first seismic design rules were introduced and were therefore constructed without consideration of modern seismic design rules. Due to their particular features such as high stone masonry walls and large span vaults as well as timber floors they are particularly vulnerable to earthquakes and may present an inacceptable seismic risk to persons and to the cultural value of the building itself. The performance states and protection objectives of seismic design codes developed for ordinary buildings do not address the particularities of cultural heritage buildings (Laupper et al., 2004). The aspects to be considered span the following topics:

- Safeguarding documentation: In case of damage or destruction, the safeguarding documentation should allow the reconstruction of immovable and movable cultural property. It should be redundantly conserved in shelters (FOCP, 2014).
- Protection of people: Cultural heritage buildings are often sacred structures or museums. As a result and unlike for most ordinary buildings, the number of people in or around the cultural

[1] Wenk E.u.B., Zurich, wenk@member-sia.ch
[2] Assistant Professor, Earthquake Engineering and Structural Dynamics Laboratory (EESD), School of Architectural, Civil and Environmental Engineering (ENAC), École Polytechnique Fédérale de Lausanne (EPFL), katrin.beyer@epfl.ch

heritage building can vary largely between time of day / weekday / season. The number of casualties in the event of an earthquake has to be limited to acceptable levels of individual and collective risks by retrofit measures or by restricting people's access to the building.

- Conservation of the original structure: To preserve not only the structure's appearance but also its original fabric, interventions should be kept to a minimum. If interventions are conducted, they should be ideally reversible.
- Structural safety of the structure: To maintain the structural integrity for a chosen return period, it is often necessary to put retrofit measures in place. However, these measures often significantly affect appearance and the structure's fabric. Many retrofit measures are therefore in direct conflict with the objective to conserve the original structure.
- Costs of the measures and their proportionality to the importance of the cultural heritage building.

Protecting cultural heritage buildings against earthquake damage is therefore a particularly challenging task since a much larger range of aspects needs to be addressed than when normal buildings are concerned. Furthermore, several stakeholders are typically involved in the conservation of cultural heritage buildings. These can include building owner, structural engineer, architect, curator of monuments, local and national authorities to name the most important. This paper outlines the authors' thoughts and considerations with regard to the conservation of cultural heritage buildings in the light of the low to moderate seismic hazard in Switzerland. The paper was motivated by the need of a strategy for the Swiss cultural heritage building stock. It starts with a brief overview on the classification of Swiss heritage buildings and a review on performance limit states for ordinary buildings. It then looks at the particularities of heritage buildings and the most important limit states, where it draws significantely from the recently completed European project "Perpetuate" by Calderini et al. (2012). It proposes a performance state matrix for the seismic assessment of heritage buildings as a function of the importance category of the heritage site giving due considerations to different conservation strategies and life safety protection requirements of occupants and visitors. With regard to the latter it focuses on the seismic risk in regions of low to moderate seismicity and extends the innovative Swiss approach for weighing off the minimum life safety requirements (Kölz and Schneider, 2005), the retrofit costs and benefits of ordinary existing buildings to cultural heritage buildings.

PERFORMANCE STATES FOR ORDINARY BUILDINGS

For buildings, different codes propose sets of performance limit states in function of ground motion levels. As an example, Figure 1 shows the performance limit states defined by FEMA 356 (2000) for the seismic rehabilitation of buildings in general. These performance limit states were defined to guarantee an acceptable building behaviour under a large range of possible ground motions. Depending on the importance of the building, different sets of objective levels can be selected as represented by the diagonals "Limited Objectives", "Basic Objectives", and "Enhanced Objectives" in Figure 1.

The "Basic Objectives" serve as a reference level considering (i) the protection of people for seismic events with a return period of 475 years, (ii) the limit of structural and non-structural damage and therefore economic losses for events with shorter return periods; and (iii) the collapse prevention of the structure for an event with a return period of 2500 years. When designing rehabilitation measures, typically only the first of the three limit states, i.e., the life safety limit state, is addressed explicitly. It is then assumed that this performance limit governs the design of the rehabilitation measures and that the other limit states are fulfilled if the life safety design check is satisfied.

Rehabilitation measures of buildings with a larger importance, i.e., buildings that are frequented by a large number of people or buildings that are essential for the functioning of the society, are designed for "Enhanced Objectives" considering longer return periods. For rehabilitation of existing buildings, lower ground motion levels are in general accepted compared to the levels for the design of new buildings as discussed in the following Section "Risk Acceptance". This approach is designated by the domain "Limited Objectives" of the matrix, which is marked in red in Figure 1. FEMA 356 does not give any guidance when the "Limited Objectives" are acceptable.

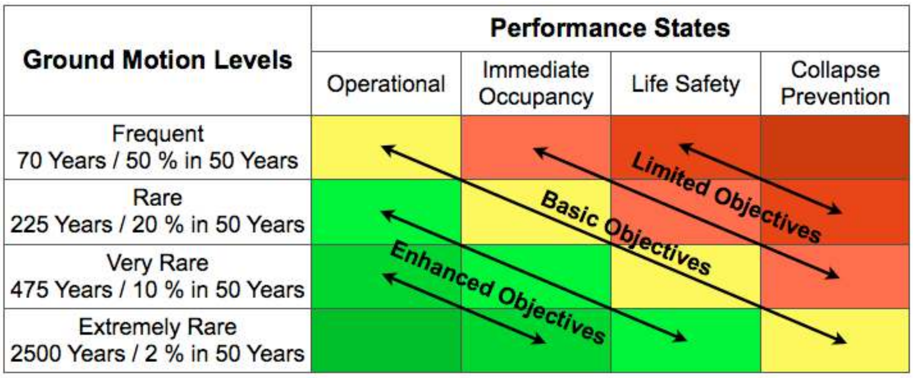

Figure 1. Rehabilitation objectives for buildings (adapted from FEMA 356 (2000))

RISK ACCEPTANCE

Already the seismic retrofit of ordinary buildings poses significant challenges: While the original construction fabric does not need to be preserved and therefore a large range of retrofit measures may be considered, retrofitting all buildings that reach lower seismic performance levels than prescribed by the current code would be too costly. In Switzerland, approximately 80 % of the existing building stock were constructed before modern seismic design guidelines were introduced in 1989 and most of these buildings would need to be retrofitted if one would impose the same requirements as for new buildings. Case studies of retrofitted buildings in zones of low to medium seismicity in Switzerland showed retrofitting costs up to 30 % of the building value (Wenk, 2008). These costs may become disproportionally high in relation to the risk reduction that can be achieved by retrofitting. To avoid an inefficient allocation of socio-economic resources, a practical risk-based approach was introduced in the Swiss Prestandard SIA 2018 (2004), which accepts "Limited Objectives" for seismic assessement and retrofitting. These "Limited Objectives" result in a more frequent ground motion level than 10 % in 50 years for the Life Safety performance state. The acceptable level is based on the evaluation of the risks to people. For this purpose, a distinction is made between individual and collective risks (Schneider, 2000). The following paragraphs summarise briefly this Swiss approach; detailed information on this approach can be found in Kölz and Schneider (2005).

Individual Risk

The individual risk is the risk experienced by an individual person in certain situations. Table 1 summarizes individual risks for various activities or exposures expressed as mean probability of death per year. Age dependent factors clearly dominate the individual risk as can be seen in Table 2. The level of risk that an average person considers as acceptable depends on two factors: (i) whether the exposure to this risk is voluntary or involuntary; (ii) in case of a voluntary exposure if the risk can be reduced by appropriate behaviour. For involuntary exposures people accept only smaller levels of risk than for voluntary exposures. For involuntary exposures without the possibility to influence the risk, such as structural safety of existing buildings, an individual risk of 10^{-5} per year is deemed acceptable according to the Swiss Standard SIA 269 (2011). This risk level was derived from comparisons with other risks to which people are involuntarily exposed, such as fire in buildings.

New buildings designed according to the seismic specifications in the Swiss Standard SIA 261 (2003) lead to an individual risk of 10^{-6} per year (SIA 269/8, 2014). Based on probabilistic seismic risk studies, it was concluded that approximately a capacity corresponding to a quarter of the design forces or design displacements for new buildings would lead to an individual risk of 10^{-5} per year (Vogel and Kölz 2005). The ratio of the capacity of the existing building to the minimum capacity required for new buildings is called compliance factor α_{eff}. It is a measure which quantifies up to which level the existing building meets the seismic design requirements for new constructions . The compliance factor α_{eff} is a key quantity in the Swiss seismic assessment procedure for existing structures.

Table 1. Mean probability of death per person and year for various activities or exposures (adapted from Schneider, 2000)

Activity or exposure	Probability of death
Smokers: 20 cigarettes a day	$400 \cdot 10^{-5}$
Drinkers: 1 bottle of wine a day	$300 \cdot 10^{-5}$
Motorcycle sport	$150 \cdot 10^{-5}$
Delta flying or paragliding as hobby	$100 \cdot 10^{-5}$
20 to 24 years old car drivers	$20 \cdot 10^{-5}$
Pedestrians, household workers	$10 \cdot 10^{-5}$
10,000 km/year car driving	$10 \cdot 10^{-5}$
Mountain hiking	$5 \cdot 10^{-5}$
10,000 km/year motorway driving	$3 \cdot 10^{-5}$
Plane crash per flight	$1 \cdot 10^{-5}$
Living in buildings: Death by fire	$1 \cdot 10^{-5}$
10,000 km/year train travelling	$1 \cdot 10^{-5}$
Death by earthquakes in California	$0.2 \cdot 10^{-5}$
Lightning strike	$0.1 \cdot 10^{-5}$

Table 2. Mean probability of death of a person and year in function of its age (BFS, 2014)

Age group in years	Probability of death
1 - 14	$9 \cdot 10^{-5}$
15 - 44	$50 \cdot 10^{-5}$
45 - 64	$350 \cdot 10^{-5}$
65 - 84	$2300 \cdot 10^{-5}$
85 and older	$15000 \cdot 10^{-5}$

Collective Risk

The collective or societal risk is the total risk to persons considering all scenarios for a specific hazard with their probability of occurrence. In the case of seismic hazard, the collective risk for a certain area or building is usually expressed by the number of deaths per year due to earthquakes. Measures to reduce the collective risk should be excecuted as long as their cost does not become disproportional with respect to the achieved reduction of risk. To find a reasonable value for the life saving costs, different safety measures to reduce man-made and natural risks are compared in Table 3. The life saving costs reflect a certain consensus within the society on how much should be spent for preventive measures to reduce the number of deaths in future disasters. The life saving costs are in general higher for man-made than for natural risks and they are much higher for very seldom, large events than for more frequent events where each single event causes only very few casualties. In addition, the degree of self-determination plays a major role in how risks are perceived and therefore on the life saving costs. As shown in Table 3, if persons are subjected completely involuntarily to the risk, the life saving costs are higher than for more voluntary conditions.

The Swiss Standard SIA 269 (2011) gives a range between 3 and 10 million CHF for proportional life saving costs for the assessment and retrofitting of existing structures with respect to all actions. According to SIA 269/8 (2014), the upper limit of 10 million CHF should be assumed as a minimum value when computing the proportional seismic retrofitting costs. In other words, assessment and retrofitting costs of 10 million CHF are considered proportional, if the retrofit saves one person’s life during the remaining useful life of the building for the considered seismic hazard. Hence, retrofit measures up to this limit should be executed. Note that – due to the low seismic hazard – often only a fraction of a life can be safed by retrofit measures and therefore retrofit measures costing considerably less than 10 million CHF may be proportional. The risk analysis according to SIA 269/8 (2014) is based on the number of deaths without considering explicitly the number of injured persons, i.e. the life saving costs of 10 million CHF per life include the costs of injured people assuming that each death leads also to a certain number of injured people..

Table 3. Comparison of life saving costs per human life saved
(adapted from Katarisk, 2003 and Schneider and Schlatter, 2007)

Safety measure	Life Saving Costs in CHF
Multiple vaccinations in the 3rd World	100
Installation of x-ray equipment	2'000
Wearing motorcycle helmet	5'000
Providing cardio-equipped ambulances	10'000
Tuberculosis screening	20'000
Deployment of rescue helicopters	50'000
Seat belts in cars	100'000
Rehabilitation of road intersections	200'000
Providing kidney dialysis units	300'000
Structural safety in buildings	500'000
Road traffic safety US	500'000
Railroad crossing safety in Germany	1'000'000
Swiss Structural Standard SIA 269	3'000'000
Tunnel safety in new Swiss alpine tunnels	5'000'000
Tunnel safety in new tunnels in Germany	5'000'000
Swiss Seismic Standard SIA 269/8	10'000'000
Transportation of hazardous materials by train in Switzerland	20'000'000
Mining safety USA	20'000'000
DC-10 grounding USA	50'000'000
Tall building regulations UK	100'000'000
Asbestos removal in school buildings in Switzerland	1'000'000'000

Compliance Factor vs. Return Period

Figure 3 shows hazard curves for three different frequencies of oscillators (peak ground acceleration (PGA), 2.5 Hz, 1.0 Hz) as well as the average for the three frequencies at a typical site in the lowest seismic zone Z1 of Switzerland.

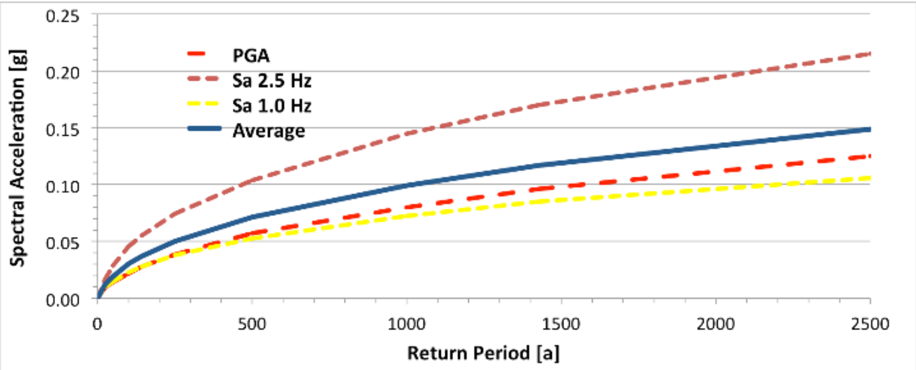

Figure 3. Spectral horizontal accelerations vs. return period for the lowest seismic zone Z1

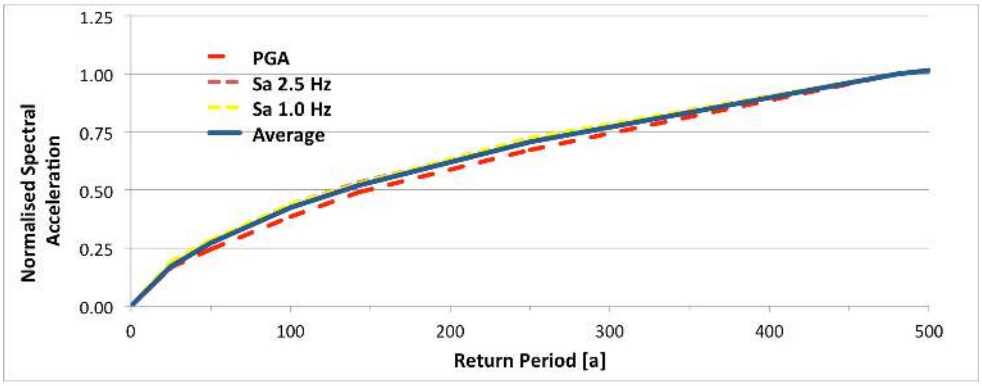

Figure 4. Normalised spectral horizontal accelerations vs. return period for the lowest seismic zone Z1

The curves in Figure 3 are based on the seismic hazard evaluation of the site Mühleberg (Swissnuclear, 2011). Figure 4 shows the same curves but this time normalised with regard to their spectral values for a 475 years return period. The normalized curves are nearly identical, i.e. the variation of the normalised spectral acceleration with return period is approximately independent of the frequency of the oscillator.
The normalised curves in Figure 4 can also be interpreted as the variation of the compliance factor α_{eff} of an existing building which can satisfy the life safety performance state for the seismic action of a certain return period. For a return period of 475 years, the design level for an ordinary new building, the compliance factor reaches α_{eff} = 1.0. As shown in the Section "Individual Risk", a compliance factor of $\alpha_{eff} \geq 0.25$ will lead to an individual risk not higher than 10^{-5} per year. According to Figure 4, a return period of approximatively 50 years leads to approximately 25 % of the spectral acceleration corresponding to a return period of 475 years. Hence, the minimum safety level for individual risk in an existing building is reached if the life safety requirements are fulfilled for a return period of 50 years.

IMPORTANCE CATEGORIES OF CULTURAL HERITAGE BUILDINGS

To determine the appropriate level of seismic protection, cultural heritage buildings are classified according to their importance. The proposed classification in importance categories follows the same well established criteria of protection of cultural heritage for other risks than seismic. In Switzerland, the Ordinance for the Protection of Cultural Property in the Event of Armed Conflict (1984) provides the following four categories in descending order of importance:

- Cultural property of international importance: Category AA,
- Cultural property of national importance: Category A,
- Cultural property of regional importance: Category B,
- Cultural property of local importance: Category C.

Figure 5 shows examples of cultural heritage buildings in Switzerland for different importance categories: The church St. Peter and Paul in Sarnen OW, a baroque sacral building of national importance built in the middle of the 18th century; the Leaning Tower of the St. Mauritius church in St. Moritz, a Romanesque sacral building of regional importance built in the 13th century; and the Blaesi school building in Basel, constructed in the 1930s in natural stone masonry with timber floors, as a representative of the many buildings of local importance.

The National Authorities are responsible for creating and updating the inventory of cultural property in the four importance categories. In Switzerland, there are currently 1647 objects of national, 6617 objects of regional, and an unkown number of local importance (FOCP, 2014).

Figure 5. Three examples of cultural heritage buildings in Switzerland: Church St. Peter and Paul in Sarnen OW (Category A, left), Leaning Tower of St. Moritz GR (Category B, center), and Blaesi school building in Basel (Category C, right)

PERFORMANCE STATES FOR CULTURAL HERITAGE BUILDINGS

Calderini et al. (2013) promote that in performance-based seismic assessment of cultural heritage buildings the conservation and safety of people are assessed in an integral approach and define three types of performance limits that account for the different aspects to be considered: Performance limits describing the effects on the building's occupancy / use and life safety, (ii) performance limits related to the building conservation, and (iii) performance limits to the conservation of artistic assets in the building (Figures 6 and 7).

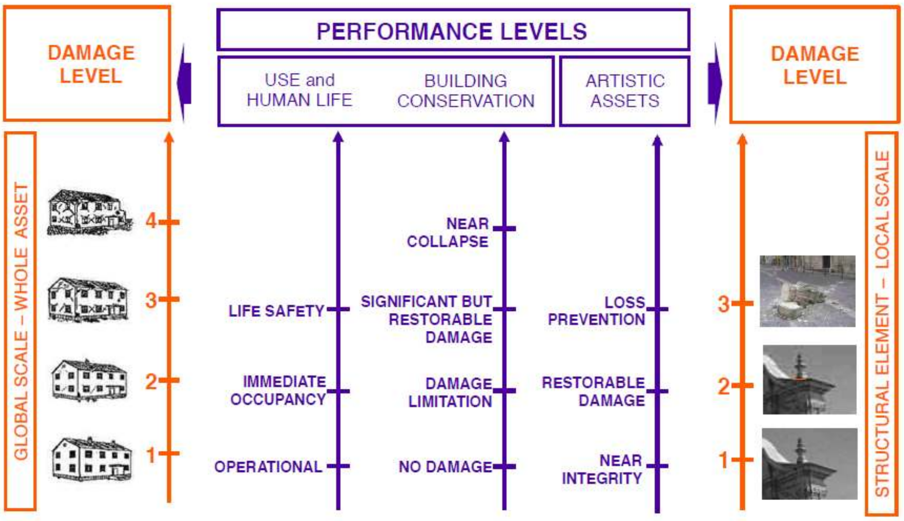

Figure 6. PERPETUATE: Performance levels and damage levels for cultural heritage buildings (Calderini et al., 2013)

	Use and Human life		Architectonic assets		Artistic assets	
$T_{RD,PLi} / \gamma_k$ (k=U,B,A)	Immediate Occupancy	Life Safety	Significant but restorable damage	Near Collapse	Restorable Damage	Loss Prevention
$72/\gamma_k$	2U				2A	
$475/\gamma_k$		3U	3B			3A
$2475/\gamma_k$				4B		

Figure 7. PERPETUATE: Return periods for cultural heritage buildings. The importance coefficient γ_k is related to the use, the archetonic and artistic value of the building and its assets (Calderini et al., 2013)

The Swiss approach builds on these limit states. To account for the low to moderate seismicity in Switzerland and to adopt it to the seismic assessment framework of ordinary buildings, the following amendments are proposed:

- To simplify the application of the method, the importance coefficient γ_k, which modifies the return period for a particular performance level, is directly related to the classification of the heritage building in the four importance categories (AA/A/B/C) and a matrix of performance states according to FEMA 356 proposed (Figure 8).
- The return period of the lowest ground motion level, i.e. "Frequent", was reduced from 70 years in Figure 1 to 50 years in Figure 8 reflecting the minimum requirement of individual risk for the performance state "Restorable Damage" of ordinary existing buildings with low occupancy according to SIA 269/8 (2014); see discussion in the Section "Compliance Factor vs. Return Period".

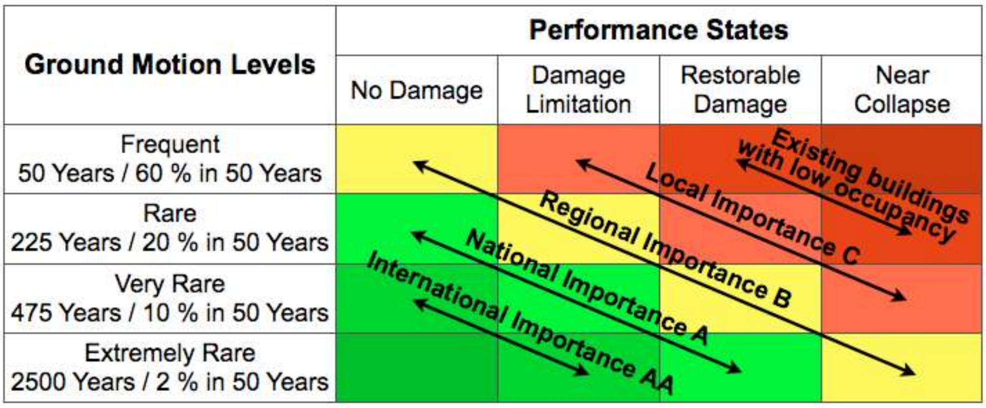

Figure 8. Proposed performance states for cultural heritage buildings

The proposed performance matrix allows to differentiate between the level of seismic protection for the four importance categories (AA/A/B/C) of cultural heritage builings, each of one represented by a diagonal in Figure 8. For the lowest importance category C of cultural property, the level of seismic protection should at least reach the required minimum code level for ordinary existing buildings of importance category I or II according to Swiss Standard SIA 269/8 (2014). For the categories of higher importance, the return periods for the performance levels are scaled to less frequent ground motion levels. For importance category B of cultural property, the proposed performance state corresponds to the required code level for ordinary new buildings, as marked in yellow in Figure 8. For the two highest importance category AA and A of cultural property, higher performance states leading to "No Damage" for the grond motion levels "Rare" or even for "Very Rare" are proposed.

The highest diagonal in Figure 8 represents the minimum level of seismic protection for ordinary existing buildings with low occupancy according to SIA 269/8 (2014). They have to fulfill the performance state "Restorable Damage" which corresponds to the performance state "Life Safety" (Figure 1) for the grond motion level "Frequent". Then the individual risk is acceptable as discussed in the Section "Compliance Factor vs. Return Period".

If the seismic assessment of the structure shows that its performance complies with the performance limits defined in Figure 8, no further measures are required. Heritage buildings of category C are accepted as sufficiently safe even though they do not meet the required code level for ordinary new buildings consistent with the general relaxation of code requirements for existing buildings (SIA 269/8, 2014). As they fulfill the performance states for more seldom ground motion levels than ordinary existing buildings with low occupancy, they can be accepted even with higher occupany. For the higher importance categories (AA/A/B) of cultural property, the performance level would then be equal or above the code level for ordinary new buildings.

If the seismic assessment reveals that not even the requirements for ordinary existing buildings with low occupancy in Figure 8 are satisfied, immediate measures are required. Such measures can comprise retrofit measures or the restriction of access to the heritage site. According to Swiss Standard SIA 269/8, the average occupancy has to be kept below 0.2 persons and the maximum number of persons which are staying in the building has to be kept below 10 persons if the minimum requirements for individual risk are not met.

If the seismic performance of the building is above the level for ordinary existing buildings with low occupancy but still below the proposed diagonal line of its category in Figure 8, several conservation strategies are thinkable. These strategies are discussed in the following section.

CONSERVATION STRATEGIES FOR CULTURAL HERITAGE BUILDINGS

Seismic conservation strategies for cultural heritage buildings can be directed towards two opposite objectives, i.e., (i) the retrofit of the structure to achieve the required performance limit state (Figure 8); or (ii) avoidance of any intervention but opting instead for the safeguarding documentation of the structure allowing hence its reconstruction in the event of an earthquake that partially or entirely destroys the structure. As outlined in the previous section, a limit on the latter is set by life safety considerations, which must comply with ordinary existing buildings giving due considerations to individual and collective risks to persons. In zones of low to moderate seismicity, this limit is rather low and could be satisfied by an important share of cultural heritage buildings. If the risk does not satisfy life safety requirements, retrofit measures are necessary that guarantee the same level of life safety protection as for ordinary existing buildings. If this is not feasible or too costly, the heritage site must be closed to the public. Hence, the performance of a heritage building must not be more risky to its occupants or visitors than that of an ordinary existing building while the more stringent performance requirements result from its cultural heritage value (categories AA/A/B/C).

The choice of the conservation strategy depends on considerations on the impact of the required interventions on appearance and fabric and costs and their proportionality. The conservation strategy should be developed by structural engineers, architects, curators of monuments, and other stakeholders of the heritage site. During this phase of decision making, an effective and clear communication between the different parties is essential. Experience has shown that as tool for the communication between stakeholders, the elaboration of different scenarios work often best. Applying different conservation strategies, the scenarios should illustrate (i) interventions and their costs and effect on appearance and the structure's fabric, (ii) the consequence for the use of the structure, (iii) the expected damage for seismic events of different return periods, and (iv) the reconstruction costs. Example strategies could for example be:

- No intervention: Conservation of the existing state without any intervention, safeguarding documentation of the structure so that it can be reconstructed. Significant damage expected for relatively short return periods. Restricted use to prevent a larger crowd of people in the building (e.g. closed to the public) if criteria of personal risks are not met in the existing state.
- Minimum intervention: Minimum interventions which are required to permit the full use (e.g. completely open to the public, use for large assembles), safeguarding documentation of the structure so that it can be reconstructed in the event of rare seismic scenarios. This approach corresponds to that of ordinary buildings not protected as cultural heritage.
- Intermediate intervention: Interventions to reach the level of seismic protection provided in the performance matrix for a lower importance category than the category of the heritage building (Figure 8). Safeguarding documentation of the structure so that it can be reconstructed in the event of rare seismic scenarios.
- Maximum intervention: Interventions to reach the level of seismic protection provided in the performance matrix for its importance category (Figure 8). Interventions do not only guarantee full use but also the structure's integrity in the event of very rare seismic scenarios.

The conservation strategy should always comprise a certain safeguarding documentation of the structure and its contents. Special consideration must be given to the long-term preservation of the documents in shelters, the formats of the documents, the keeping of several copies, etc. To illustrate the possible choices of conservation strategies, Figure 9 shows, as an example, the recommended performance states for a category A heritage building in lighter green between the diagonal limits "Ordinary Buildings" and "National Importance A". The performance state "Near Collapse" below the minimum requirement for ordinary existing buildings marked in red is not acceptable due to life safety requirements. The higher performance state than those defined by the diagonal "National Importance A" are, of course, also acceptable but usually not reachable with reasonable measures. The range in between the diagonal "Ordinary Buildings" and "National Importance A" are feasible. Any significant distance from the diagonal "National Importance A" should be compensated by a safeguarding documentation of the entire building.

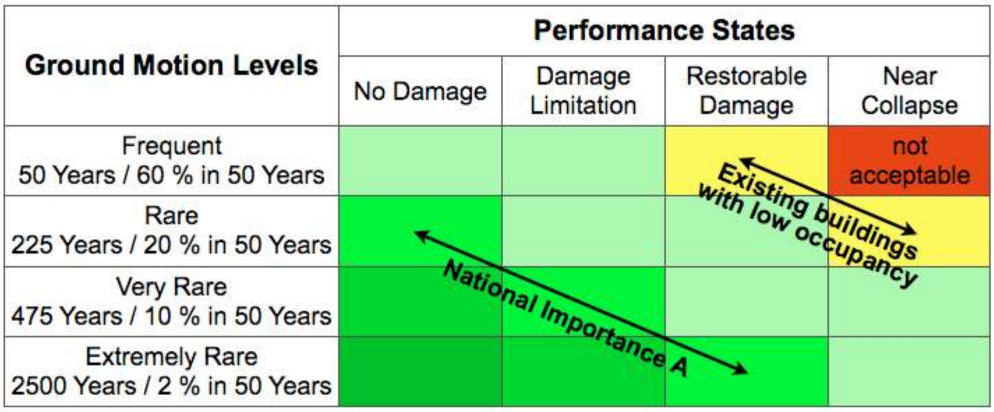

Figure 9. Proposed performance objectives for conservation strategies of cultural heritage buildings of importance category A

CONCLUSIONS

The paper outlines a framework for a seismic conservation strategy for Swiss cultural heritage sites. The paper draws from fundamental concepts of the Perpetuate project (Calderini et al., 2013), FEMA 356 (2000) and SIA 269/8 (2014). The former provides in particular the performance state matrix for existing buildings and the principal idea that it is permissible that existing buildings comply with lower performance limits than new buildings. The SIA 269/8 is the new Swiss seismic code for existing buildings, which introduced new concepts on the proportionality of rehabilitation costs and minimum life safety standards. The latter are also adopted in the framework for seismic conservation strategies proposed in this paper. The principal ideas of this framework relate to:

(i) minimum performance level due to life safety requirements;
(ii) nominal performance levels as a function of the importance category of the heritage site (local / regional / national / international importance;
(iii) choice of seismic conservation strategy for performance levels between minimum and nominal permissible.

Two opposed seismic conservation strategies were outlined while many intermediate strategies exist. The first strategy aims at reducing damage in the event of an earthquake and at reaching the nominal performance levels that are defined as a function of the importance category of the heritage site. This strategy typically results in significant rehabilitation measures. The second strategy aims at keeping the interventions to an absolute minimum, i.e., by introducing only those that are necessary to reach life safety requirements. No further measures are taken in order to keep the impact on the structure's fabric and appearance to an absolute minimum. As a result, one must accept that the building experiences significant damage for events with return periods as low as 50 years. To account for this risk, the structure must be carefully documented to allow its reconstruction.

REFERENCES

BFS (2014) Sterbefälle und Sterbeziffern wichtiger Todesursachen nach Alter 2012, Statistisches Lexikon der Schweiz, www.bfs.admin.ch, Bern, Switzerland, visited 1.7.2014

Calderini C., Cattari S., Lagomarsino S., Marrè Brunenghi M. (2013) PERPETUATE**,** PERformance-based aPproach to Earthquake proTection of cUlturAl heriTage in European and mediterranean countries, Final Report D42, Seventh Framework Programme, EU Commission, Brussels

Eurocode 8-1 (2004) Design of Structures for Earthquake Resistance - Part 1: General Rules, Seismic Actions and Rules for Buildings, EN 1998-1, European Committee for Standardization, Brussels

Eurocode 8-3 (2005) Design of Structures for Earthquake Resistance - Part 3: Assessment and Retrofitting of Buildings, EN 1998-3, European Committee for Standardization, Brussels

FEMA 356 (2000) Prestandard and Commentary for the Seismic Rehabilitation of Buildings, Federal Emergency Management Agency (FEMA), Washington D.C.

FOCP (2014) Federal Office for Civil Protection, www.bevoelkerungsschutz.admin.ch/internet/bs/en/home/themen/kgs/schutzmassnahmen.html, visited 14.4.2014

Laupper H et al. (2004) Expertenbericht: Erdbeben und Kulturgüter, Arbeitsgruppe Erdbeben und Kulturgüter, Bundesamt für Bevölkerungsschutz (BABS), Bern, Switzerland

Katarisk (2003) KATARISK: Katastrophen und Notlagen in der Schweiz, Erläuterung der Methode, Bundesamt für Bevölkerungsschutz BABS, Bern, Switzerland

Kölz E. and Schneider J. (2005): Beurteilung der Erdbebensicherheit bestehender Gebäude – der risikobasierte Ansatz des Schweizer Merkblatts SIA 2018, *Bautechnik* 82 (2005) Heft 8

Ordinance (1984) Protection of Cultural Property in the Event of Armed Conflict, Swiss Federal Ordinance of 17 October 1984, SR 520.31, Bern, Switzerland

Schneider J. (2000) Safety – A Matter of Risk, Cost, and Consensus, *Structural Engineering International*, Vol. 10 No. 4

Schneider J. and Schlatter H.-P. (2007) Sicherheit und Zuverlässigkeit im Bauwesen: Grundwissen für Ingenieure, vdf Hochschulverlag AG an der ETH Zürich

SIA 261 (2014) Swiss Standard SIA 269: Actions on Structures, Swiss Society of Engineers and Architects, Zurich, Switzerland

SIA 269 (2011) Swiss Standard SIA 269: Existing Structures – Basis for Examination and Interventions, Swiss Society of Engineers and Architects, Zurich, Switzerland

SIA 269/8 (2014) Swiss Standard SIA 269/8: Existing Structures – Earthquakes, Enquiry version, Swiss Society of Engineers and Architects, Zurich, Switzerland

SIA 2018 (2004) Pre-Standard SIA 2018: Examination of existing buildings with regards to earthquakes. Swiss Society of Engineers and Architects, Zurich, Switzerland

Swissnuclear (2011) Intermediate Seismic Hazard (May 2011) Evaluation of an intermediate seismic hazard for the existing Swiss nuclear power plants, Olten, Switzerland

Vogel T., Kölz E. (2005) Evaluation of existing buildings with respect to earthquake risks, Proceedings ICOSSAR'05, 9th International Conference on Structural Safety and Reliability, Rome, June 19-23, 2005. In: ICOSSAR 2005, G. Augusti, G.I. Schuëller, M. Ciampoli (eds), Millpress, Rotterdam

Wenk T. (2008) Seismic retrofitting of structures, Strategies and collection of examples in Switzerland, *Environmental studies No. 0832*, Federal Office for the Environment, Bern, Switzerland

Wenk T. (2014) "Seismic assessment based on cost-benefit analysis," Proceedings of the 2nd European Conference on Earthquake Engineering and Seismology, Istanbul, Turkey