SEISMIC SAFETY OF MONUMENTS - SWISS INTERDISCIPLINARY GUIDELINES

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ABSTRACT

Switzerland is a country of low to moderate seismicity. Modern seismic standards for new buildings were introduced in 2003. Seismic assessment and proportional retrofit of existing buildings is constantly improving since introduction of the Swiss Prestandard SIA 2018 in 2004, merged into the new Code SIA 269/8 “Maintenance of structures – earthquake” in 2017. Monuments - buildings as testimonials of past epochs deserving protection - are more and more moving into the focus. Diverging ideas how to approach retrofitting on monuments, different interpretations of protection objectives and the evaluation of proportional interventions have caused conflicts in the solution finding process in the past. Interdisciplinary guidelines, kick-started and financed by the Swiss Federal Office for the Environment, will be published in 2019 with the focus to guide the practice in this complex topic. The major tool for the interdisciplinary approach offered to the practice by the guidelines presents a model process for construction projects of monuments. This paper presents a theoretical presentation of these Swiss guidelines for seismic safety of monuments. After an introduction to the Swiss basics and the framework of the involved disciplines, the main part of the paper wants to give an understanding of the proposed model process flow. By the time of the presentation a concrete example of an actual construction project will be presented where the model process is applied and documented.

Keywords: Earthquake protection, monuments; interdisciplinarity; Assessment; retrofit; Proportional measures.

1. INTRODUCTION

Earthquake protection of existing buildings experiences a strong improvement in Switzerland since the Prestandard SIA 2018 was published in 2004. Monuments – buildings as testimonials of past epochs deserving protection - are moving increasingly into focus. Diverging ideas how to approach retrofitting on monuments, different interpretations of protection objectives and the evaluation of proportional interventions often cause difficulties and conflicts in the solution finding process. It’s nonetheless unquestioned among the involved disciplines that a minimal protection of people has to be guaranteed.

The most important players in earthquake protection of existing buildings and especially of monuments are the building owners. They are responsible for the condition assessment of the monument, its long-term maintenance and the realization of necessary retrofitting measures. It rests on them to examine the monument regarding seismic safety and – if necessary – in cooperation with several disciplines to induce and realize the development of retrofitting concepts that are suitable to the object of consideration, suitable to preservation principles and economical.

The state of knowledge of the involved professionals differs. Structural engineers have no or very rudimentary knowledge about monuments, the cultural value of their building structure, the principles of their care and maintenance. Monument conservators vice versa are not familiar with the subject of earthquake protection and its requirements. That is where the guidelines are set. They introduce to the subject, formulate principles and offer concrete details and instructions how efforts in earthquake

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The protection of monuments can be proceeded. These guidelines for the practice aim to guide to efficient design with the necessary carefulness in protecting the monument – in all protective meanings. The guidelines address all involved players and include three chapters: The first chapter basics and framework is supposed to promote the mutual understanding of the background, ways of thinking and principles as well as the possibilities of decision making of the respective players. The second part of the guidelines seismic safety of monuments – a process tries to outline an interdisciplinary procedure that can serve as an orientation in construction projects. The third practical chapter Collection of examples drafts different projects partially with realized measurements and compares the taken procedures with the recommended model process of the guidelines. The very different examples are supposed to meet the difficulty that dealing with monuments always represents a specific approach for every discipline. Figure 1 shows two buildings that were used as examples.

Figure 1: Award winning example of interdisciplinary teamwork. School building “Quaderschulhaus” in Chur (Swiss Foundation for Structural Dynamics and Earthquake Engineering, www.baudyn.ch), above; Application of the proposed model process during the renovation project of the conference center of the City of Biel, below.

The guidelines have been developed by the earthquake mitigation section of the Federal Office for the Environment in cooperation with the Federal Office of Culture and the Federal Office for Civil Protection accompanied by an interdisciplinary board of representatives of the Confederation, the cantons, the Swiss research community and experts in earthquake engineering, architecture, monument conversation and heritage protection.
2. BASICS AND FRAMEWORK

2.1 Seismic hazard and earthquake protection in Switzerland

Strong earthquakes are relatively rare in Switzerland but definitely possible all over the country. The strength and frequency and therefore the hazard at one location varies depending on the geographical region; particularly affected are the Wallis in Southern Switzerland, the region around Basel in the Northwest, central Switzerland, the St. Galler Rheintal and the canton Grison in the East, as shown in Figure 2.

Even if there has not occurred a major earthquake in the last decades (1964 Sarnen OW, Magnitude M 5.7; 1946 Sierre VS, M 5.8), damaging earthquakes in larger time intervals have to be expected. The aftermath of foreign seismic events is therefore important and can be especially instructive when the strength of the earthquake and/or the construction (vulnerability) are comparable to Swiss conditions (z. B. 2009 L’Aquila I, M 6.3; 2010/2011 Christchurch NZL, M 7.1/6.3). The influence of subsoil conditions on the ground motion is widely underrated. Local, geological and topographic conditions are responsible for short distanced extensive modifications of the amplitude, the frequency and the duration of the ground motion of an earthquake.

In spite of the moderate seismicity in Switzerland its seismic risk, as a “product” of hazard, subsoil, vulnerability and values of protection, is comparatively high, particularly because of the dense settlement and the high concentration of values in the country (Figure 3).
Traditionally, buildings in Switzerland have been constructed to withstand vertical loads like dead, live or snow loads. Apart from wind loads horizontal loads have not been taken into consideration when designing the structure. Even if a certain basic resistance against horizontal loads exists the majority of older buildings is presumed do not comply with modern code requirements concerning seismic loads. Typical weak points of existing buildings in Switzerland are soft-storeys, unsymmetrical stiffening, irregularities, masonry structures with unfavorable deformability and flexible floors.

The Swiss buildings codes have been revised three times in the last four decades concerning seismic design requirements. The Swiss code generations of 1970, 1989 and 2003 showed an increasing consideration of seismic loads and implemented newest expertise of earthquake engineering and seismology. Still, before 2003, the load case earthquake was never or insufficiently taken into consideration in architectural concepts and structural design. The Swiss Prestandard SIA 2018 “Verification of existing buildings concerning earthquakes” (Swiss Society of Engineers and Architects sia 2004), gave an answer to question how the practice should deal with existing buildings that had not been designed earthquake-resistant. In 2017 the Prestandard merged into the new Code SIA 269/8 “Maintenance of structures – earthquake” (sia 2017) which joins the code sequence based on Code SIA 269 “Maintenance of structures” (sia 2011). According to SIA 269 existing buildings have to be principally verified if new technical expertise or code requirements have been established.

The building stock of Switzerland did not change much since 1970. 55 % of all buildings have been constructed before 1970. 24 % of the buildings have been constructed between 1971 and 1989. 21 % of the buildings have been constructed since 1990 and only 5 % of them have been constructed according to the actual code standards of 2003. Hence, approximately 95% of the building stock has been constructed before 2003. Among these buildings the design was proceeded without appropriate consideration of the danger through earthquakes. The seismic safety of these buildings is unknown as long as an explicit verification is not realized.

Under legal aspects earthquake protection is primarily significant for building owners, followed by architects and structural engineers that perform interventions on existing buildings. Building owners are subject to the liability of the owner of a construction according to the Swiss Civil Code (Part Five: Code of Obligations, Art. 58). Architects and structural engineers are subject of the due diligence and have to realize the work according to the state of the art (Part Five: Code of Obligations, Art. 398 resp. Art. 364). In construction trade in Switzerland earthquake protection is regulated through building laws and building codes. In the Swiss federal system the jurisdiction of building laws is liable to the cantons. The buildings codes are developed and published by the Swiss society of engineers and architects (sia) which are legally assumed to be state of the art. All 26 cantonal building laws have in common that they generally ask for “safe constructions” that do not endanger people or objects. This safety is guaranteed through the Swiss building codes.
2.2 Preservation of monuments in Switzerland

The public mandate of the preservation of monuments is principally stated in the Federal Constitution of the Swiss Confederation (Art. 78). The article regulates the responsibilities of the different public levels, namely the jurisdiction of the 26 Swiss cantons. The political context, organization, personal and financial layout differ strongly among the cantons. All cantons designate centers of competence for monument preservation who are responsible for the inventory, investigation, counselling, supervision of restorations archiving, financial contributions and public relations.

The fundamental principles in working with monuments have been published by the Federal Commission for Monument Preservation (EKD) in 2007. The "Guidelines for the preservation of built heritage in Switzerland" (EKD 2007) are aimed at experts in all relevant fields, as well as owners, architects, politicians and other interested persons. They favor the understanding of the nature of built heritage and presents the suitable measures for its long-term conservation. The guidelines were published to successfully represent the activities of the centers of competence towards the public and the politics. The guidelines and working with monuments in Switzerland is based on international charters and conventions, among others the Venice Charter for the Conservation and Restoration of Monuments and Sites from 1964, the Florence Charter “Historic Gardens” from 1981, the Washington Charter for the conservation of historic towns and urban areas from 1987, the Lausanne Charter for the protection and management of the archaeological heritage from 1990, the Granada Convention for the Protection of the Architectural Heritage of Europe from 1985 and the Revised European Convention on the Protection of the Archaeological Heritage (Valetta) from 1992. Having every generation asking new methodical questions and dealing with new parameters, these accepted standards of the discipline and the working field of preservation of monuments are verified and adapted on a regular basis.

According to the “Guidelines for the preservation of built heritage in Switzerland” monuments are immobile objects with historical testimonial value. Monuments can be testimonials of human action, historical events and developments, artistic performance, social establishments or technical achievements. Monuments are defined by their complete passed down materiality which make the authenticity. An object turns into a monument by recognizing and determining its historical testimonial value and passed down materiality. The monumental characteristic exists independently of administrative actions or inventory admission. Most of the Swiss cantons and many of the bigger communities possess monumental inventories based on the federal and cantonal laws.

Heritage protection represents an individual field of regulations and application in Switzerland. Nowadays heritage protection and relevant legal basics are founded in armed conflicts, namely the tremendous destructive aftermath of World War II. In 1954 the Hague Convention for the Protection of Cultural Property in the Event of Armed Conflict passed. Switzerland joined this convention in 1962 and committed to protect the cultural heritage both on its own ground and the grounds of the contracting partners. The Federal Act of 6 October 1966 on the Protection of Cultural Property during Armed Conflicts defined the parameters of this commitment.

Switzerland ratified the Second Protocol to the Hague Convention from 1999 in 2004. It foresees an enhanced protection of cultural heritage of particular importance. Explicitly article 5 of the 2. Protocol specifies preparatory measures taken in time of peace for the safeguarding of cultural property: these include among others the preparation of inventories. Since January 1st 2015 the Federal Act on the Protection of Cultural Property during Armed Conflicts, Disasters and Emergencies is effective. The main tasks in the protection of cultural property in Switzerland concentrate on preventive measures with regard to natural disasters like floods, landslides, avalanches or earthquakes or technically conditioned events like fires or pipe breakages. Besides the inventory of cultural property, the safety measures involve the guidance with security documentations and photographic security copies of important documents, the designation of cultural property, the establishment and operation of shelters as well as the training of specialists.
3. EARTHQUAKE PROTECTION OF MONUMENTS - A PROCESS

The planning of seismic safety measurements for monuments, in particular structural measures complying with preservation principles for historical monuments, is an iterative and interdisciplinary process, advisably happening in the context of a construction project. A construction project is hereby understood as a restoration or transformation, in other words an interventions which exceeds the regular maintenance, which affects the structure and/or is caused by a change of use.

This process consists of the following seven essential tiers:

1. Initial situation
2. Condition assessment
3. Determination of the protection goals
4. Engineering verification and evaluation of the seismic safety
5. Development of variations of solutions and elaboration of concepts of intervention
6. Intervention recommendation and decision
7. Realization

and blends into the defined phases of the planning process of constructions projects according to Swiss Standard 112 “Model for construction planning” (sia 2014).

3.1 Initial situation

The initial situation represents the start of the process and happens with the strategic planning. Based on the problem that the ownership defined in its utilization of the monument an architect is commissioned to verify the needs both by analyzing the needs and by verifying the goals of the ownership and the frame conditions. Furthermore he evaluates proceeding alternatives and different strategies to solve the problem. Finally the owner evaluates the necessity, the urgency and the wearability of the different solutions and decides about the strategy to solve the problem through the construction project.

Already at that point of time it is very relevant to question the reasonability and usefulness of the intended utilization of the monument. The occupation and function that is linked with the utilization decides majorly about the targeted level of seismic safety (protection goal) by classifying the monument into a building class according to Swiss Code SIA 261 “Actions on structures” (sia 2013). Also in this tier the monument status of the object has to be clarified. The local center of competence of monument preservation informs about the protection category of the monument.

The build-up of a team of specialists for the construction project in this tier initiates a close cooperation between all involved players. Monuments demand a much more differentiate handling than non-monumental existing buildings. Therefore the technical condition survey and preserving investigation of the construction, the technical verification and evaluation of the seismic safety, the determination of the protection goals, the variations of solutions and concepts of intervention and the intervention recommendation and decision have to be trusted to a team of designated experts led by a representative of the owner who is competent in managing monuments. The focus of the team therefore must be to periodically link together the results according to the progress of the project. If necessary the results have to be updated and major decisions need to be prepared with all experts involved.

3.2 Condition assessment

The technical condition survey and preserving investigation of the construction has to be induced before the project planning since they are the presupposition of the technical verification and evaluation of the seismic safety and the determination of the protection goals. This can only be done with an exact knowledge of the object and of the consequences of its utilization. The technical condition survey is carried out by the assigned structural engineer. The preserving investigation of the construction has to be conducted by the local center of competence of monument preservation. These studies are realized...
by both disciplines together and are coordinated. The structure, the conceptual and constructional principles and deficits as well as the properties of the used materials are significant to the structural engineer and the monument conservator. These studies have to be completed by a report that represents the basis of the project planning phase.

For sensibilisation aspects of all involved actors it is highly recommended to conduct at least one inspection in presence of the architect and the ownership.

3.3 Determination of the protection goals

The determination of the protection goals and the protection goals themselves are defined and interpreted much differently between structural engineers and monument conservators. In this tier the protection goals of both disciplines are defined independently and opposed to each other. A first mutual understanding of the most severe/highest requirements of each side is necessary to successively converge to a protection goal all players will stand for.

Based on the “Guidelines for the preservation of built heritage in Switzerland” the discipline of monument conservators applies the full preservation of the building's historic substance as a general protection goal. The determination of the protection goals in the preserving context is in any case absolved specific to the individual object and describes the vital building parts in the understanding of preservation. The protection goals are defined and bindingly determined on the base of the preserving investigation of the construction. They focus on the important parts of the building that have to be preserved and/or conserved. The extent of the protection goals depends on the importance of the monument and therefore can vary considerably. Typical protection goals can be the undiminished preservation of the external appearance, the integral conservation of a certain building part including its original surfaces or the complete preservation of an essential room structure in its appearance and materialization. Building parts and elements that are not explicitly worthy of protection can be suitable for intervention.

The protection goals in structural engineering are more of a fundamental nature and are described in the Swiss building codes. They are qualified and quantified according to code specifications. In earthquake mitigation for objects of protection the seismic safety has to respect the code requirements of new constructions. According to Swiss code SIA 261 objects of protection are defined as people, considerable material assets (buildings, infrastructures, objects of considerable economic importance, means of livelihood and cultural heritage) and the environment. For these objects the seismic risk has to be reduced to an acceptable degree. The efficiency of the measurements serves to meet the aimed security. The aimed protection goals concerning seismic safety of a building cover personal security (saving lives), damage limitation (direct damage, secondary damage, damage to intangible goods) and warranty of functional efficiency of important constructions (limitation of malfunction). The requirements of seismic safety of a new construction of building class BWK I of the Swiss codes concern the verification of structural safety under the design earthquake and the respect of conceptual and constructional measurements. The applied seismic actions have a return period of 475 years.

The requirements of seismic safety of existing constructions of building class BWK I have been defined the following according to Swiss code SIA 269/8:

The individual risk (annual probability of dying) of people in a building is \( \leq 1 \times 10^{-5} \) per year, which means 25% of seismic safety (for BWK I) compared to a new construction. When complying with the safety requirements of the individual, the protection goals of new constructions have to be strived, thus 100% of seismic safety compared to a new construction.

Existing construction of higher intended purpose of building classes BWK II and III have to meet increased protection goals considering higher return periods. Certain existing construction of building class BWK II (e.g. schools) and for all of buildings class BWK III a higher minimum compliance factor of 0.40 has to be respected. The “increased protection goals” of a building class BWK III demand additional requirements concerning functional efficiency, which are described through the warranty of
serviceability by the codes. The verification of serviceability is conducted with lower return periods.

3.4 Engineering verification and evaluation of the seismic safety

The engineering verification and evaluation of the seismic safety is executed by the assigned structural engineer. The technical verification of the seismic safety is done for the as-is state. If compulsory conceptual and constructional conditions are not met, the calculation model has to be chosen sufficiently differentiated to consider the dynamic behavior of the construction and the consequences of the lacking conditions. The technical verification is carried out under the seismic actions of the design earthquake (according to Swiss Code SIA 261) whose dimension depends on the site, the subsoil conditions and the building class of the construction. Besides the structure, nonstructural elements that endanger people, the structure or the operation of important infrastructures also have to be verified according to Swiss Code SIA 261.

According to Swiss Code SIA 269 an examination of an existing building consists of a general verification which is followed by a detailed examination, if necessary. The general examination can be executed with seismic actions based on the Swiss Code. Site-specific studies about the seismic actions should be undertaken if a detailed verification becomes necessary. They can lead to more realistic and possibly better values.

The analysis results in the determination of the so-called compliance factor of the verified as-is state $\alpha_{eff}$. This value compares the effects of seismic actions in compliance with the code with the resistance of all structural (and non-structural) members in which the smallest compliance factor $\alpha_{eff}$, hence the one of the weakest most critical element, is controlling. For example if the value of the compliance factor is equal to $\alpha_{eff} = 0.3$, the existing building has a seismic safety of 30% compared to a new construction in compliance with the code.

The evaluation of the seismic safety of the structure and the nonstructural elements is done by comparing the compliance factor of the verified as-is state with the minimum compliance factor $\alpha_{min}$.

In general the verification of the seismic safety of a monument has to be executed through a complete general verification according to Swiss Code SIA 269/8. If it leads to a compliance factor that requires measures the applied simplifications and the accuracy of the calculations have to be demonstrated. In any case it has to be evaluated if a detailed verification with differentiated structural models, deformation-based methods, non-linear analysis etc. could lead to more realistic and better results for the level of seismic safety of the as-is state.

To prepare the tier Variations of solutions and concepts of intervention the resulting seismic weaknesses of the monument have to be illustrated. That should be done schematically on the drawings of the floor plans, the elevations, the sections and façade views of the monument.

3.5 Development of variations of solutions and elaboration of concepts of intervention

Based on the condition survey and the evaluation of the seismic safety variations of solutions are developed that consider the engineering and preserving protection goals. Through interdisciplinary cooperation and evaluation a number of concrete concepts of intervention are selected.

Measurements for seismic safety on monuments can be of structural or operational nature. Operational measurements can be a restriction of use but also a complete change of use, which allows a downgrading of the monument in a lower building class because of a lower occupation. Structural measurements for example consist in interconnecting of structural components (slab and wall), in closing dilation joints, in purposely weakening a component or reducing masses. Measurements are planned by the structural engineer through interdisciplinary cooperating with the architect and the monument conservator. The planning happens iterative and with increasing detailedness.
In cooperation with the architect the structural engineer develops a rough range of variations of improving solutions. Thereby the structural engineer differs between measurements that are mandatory to fulfill minimal requirements and measurements that increase seismic safety to full code requirements. The preserving frame has to be taken into consideration as much as possible. The different approaches are compared and rated by the interdisciplinary team according to their effects on the monument, their elimination of seismic weaknesses and their compliance with building use and resources. This evaluation process is ideally documented through a matrix illustration.

The rating of the different variations of solutions allows a limitation on some few approaches that are conceptually amplified by the structural engineer in a next step.

3.6 Concepts of intervention taking into account proportionality

The consolidation to concrete concepts of intervention is again carried out by the structural engineer in close cooperation with architect and the monument conservator. For every chosen variation of solutions a variations of the concepts of interventions are prepared. The elaboration has to be done in such a detailed manner that an evaluation of the proportionality becomes possible.

A measurement is proportional in the context of preservation if the cultural value of the monument is not or only barely reduced. A measurement is proportional in the context of earthquake mitigation if it is efficient according to the codes, which means the effort (costs) is low and the benefit (risk reduction) is high. Consequently depending on the importance of the monument a much more differentiated evaluation of the proportionality of continuing measurements - in excess of the minimal requirements – becomes necessary.

Monuments have to comply with the minimal requirements of life safety just like any other building. However the differentiated evaluation of the proportionality of exceeding measures compulsory has to be executed under consideration of the cultural value through a weighing up of the proportionality. As a major criteria to evaluate a harmonized, monument-specific proportionality serves the influence on the maintenance value through the proposed measures (as-is state compared to target state). Every concept of intervention can be described by its influence on the maintenance value through a matrix where criteria of seismic design and monument preservation can be assessed. These matrixes do not base on exact mathematical methods but reflect a pragmatic and intersubjective evaluation that document the before and after of the maintenance value in a clear way. This evaluation has to be proceeded among owner, monument conservator, architect and structural engineer. Finally the comparison of the singles matrixes allows a limitation and prioritization among the different concepts of intervention.

3.7 Intervention recommendation and decision

This tier concludes in an intervention recommendation that proposes selected concepts of intervention for the further procedure including their assessed proportionality. Therefore the concepts of intervention for the mandatory and possible continuing measurements have to be worked out in detail. By means of a process of consultation the intervention recommendation is prepared for decision making of the ownership. If the intervention recommendation is supported by all players, the recommendation is transferred into a concrete construction project.

The decision of the ownership itself is based on an integral risk and project assessment. The long term consequences of the realization or omission of the measurements have to be weighed. The balancing of interests of preserving goals and earthquake safety requirements has to consider the particularity of the individual case. The emphasis of interests has to be presented transparently.
3.8 Realization

The intervention project has to be verified and adapted on site continuously throughout the realization if new knowledge occurs. An intense supervision through the monument conservator and the structural engineer of the realization of the measurements on site are strongly recommended.

4. CONCLUSIONS

The most important players in earthquake protection of monuments are the building owners. They are responsible to mandate an examination of the monument regarding seismic safety and – if necessary – in cooperation with several disciplines to induce and realize the development of retrofitting concepts that are proportional and suitable to the object of consideration and preservation principles.

The future Swiss guidelines “Earthquake protection of monuments” which will be published in early 2018 shall give each involved disciplines an understanding of their vis-à-vis, connect the specialists inside the interdisciplinary project team as well as build a bridge between the interdisciplinary project team and the ownership.

To increase the knowledge of the involved professionals a mutual understanding of the framework and background of each involved discipline is attended to build the foundation to develop suitable, proportional measurements inside the team of specialists. In presenting necessary basics - like seismic hazard and risk, earthquake protection principles and technical standards as well as legal basis in preservation and cultural heritage, principles on dealing with monuments and monument designation and assessment – and misunderstandings in the past shall be removed. With the proposed model process for the approach in earthquake protection of monuments within a construction project the interdisciplinary exchange shall be enabled.

5. REFERENCES


