Earthquake mitigation of infrastructures in Switzerland Need for action, evaluation and implementation of measures

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SUMMARY:
The seismic hazard in Switzerland is moderate, but the seismic risk is one of the largest among the natural hazards. Due to their net structure and complexity, infrastructure systems are especially vulnerable to large-area hazards like earthquakes. The Swiss Confederation has started in the year 2000 a federal earthquake risk mitigation program. As the cantons have a lot of competences in the Swiss federalism the state has only some limited legal and authorisation competences. Nevertheless there is need for action at all levels. The low awareness of earthquakes in Switzerland of the society and of buildings professional makes it difficult to standardise the implementation of risk reducing measures. A lot of simple and efficient measures are known, but need to be controlled by authorisation authorities. With sensitisation the awareness of owners and operators of infrastructure facilities must be raised so that they become active in earthquake mitigation in their own interest.

Keywords: Earthquake, Mitigation, Infrastructures, Switzerland

1. INTRODUCTION

The relevance of infrastructures, as main artery for modern societies, is growing because of the increasing population and the rising need of mobility. Infrastructures have an often underestimated economic signification. In international comparison the existing level of infrastructure systems in Switzerland is good (see [1]), but this advantage is not secured forever. Even today critic bottlenecks exist in the systems as well as weak points, which can affect the social welfare. Because of their net structure, infrastructures are especially vulnerable to large-area hazards like earthquakes. In addition to the direct losses, the failure of infrastructures can delay the response and the recovery or even make it impossible so that the extent of losses even gets worse.

When evaluating infrastructure systems the future development has to be considered as the growing demand is in contradiction to the possibilities of extension. The result is a more intensive use of the systems, which leads to capacity limits and to an increasing risk of area-wide blackouts of systems, already caused by local failures on neuralgic weak points. For the evaluation of a system the identification of those weak points is central.

2. EARTHQUAKE MITIGATION OF INFRASTRUCTURES IN SWITZERLAND

2.1. Mitigation program of the Swiss Confederation

With the goal to protect lives and properties against earthquake the Swiss Confederation has started in the year 2000 a federal earthquake risk mitigation program, which focuses on preventive and precautionary measures. This program is actualised each four years by an interdepartmental working group and presented to the Federal Council for adoption [2, 3].

In addition to the federal buildings the Swiss Federal Council has concluded among others to investigate the seismic safety of infrastructures and where necessary to improve the safety by implementation of measures. Under the lead of the coordination centre for earthquake risk mitigation of the federal office for the environment (FOEN), a work group reports on the actual state regarding the protection of important infrastructures against earthquake and identifies the further need for action. Infrastructures deliver services and products to the society, the economy and to the state. In dependence of the angle of vision the failure of nearly every infrastructure can therefore affect our society. Consequently the work group enlarged with the time its field of activity from Lifelines to infrastructures in general. In addition to the sectors within the direct competence of the federal government through its supervisory or subsidy activities, the other facilities are also taken into account. Under consideration of the responsibilities and the operational levels the following systems, especially vulnerable against earthquakes, have been prioritised for further investigations:

- Electric power utility
- Transport systems (Roadways, Railway and Airports)
- Waste water
- Gas utility
- Telecommunication systems
- Potable water

2.2. Competences and complexity of infrastructures in Switzerland

In Switzerland the protection against natural hazards is a network duty in which the state, the cantons and the communes take part. But in the field of seismic risk the Swiss constitution do not assign any competence to the state. In the Swiss federalism the cantons are in charge of the legislation and the permission delivery of construction projects. Beyond that the state has some limited legal and authorisation competences in a few sectors. The state can primarily protect its own constructions, mainly buildings, against earthquakes. The main national roads also belong to the state. The other considered infrastructures belong to the cantons, the communes or private institutions and only a few are approved by the state. Nevertheless the investigations show that there is also need for action outside of the competence field of the state.

The strongly linked and overlapping responsibilities complicate the implementation of measures as the financing, basically associated to the responsibility, is not clearly defined. Collaterally the complexity of net structures hinders the prioritisation of measures following their efficiency. In addition the growing interdependencies between different infrastructures must also be taken into account while prioritising measures. The difficulty lies also in the point of view, the system boarders and the conflicting interests between the different actors. Protection goals of a private operator may only cover financial interests. For the state in contrast, the supply security of the society comes first. In addition to those points, the really low awareness for earthquake in Switzerland of the civilians but also of the construction professionals and the owners of facilities reinforce the problematic. The Coordination Centre for earthquake mitigation of the FOEN is therefore also active in coordination and consultation of all actors linked to infrastructure systems, of course only by promotion. In the authorisation procedures of infrastructures on national level, where the state is bound to implement measures, the FOEN plays the role of specialist in earthquake mitigation for the other federal offices.

2.3. Goals and need for action

Even if infrastructures show a big complexity and interest conflicts exist, the main goal for private as for public suppliers is to reduce the damage levels following a major disaster like an earthquake as well as to reduce the time to get back to usual level of service. For sure there are also other natural hazards to consider and an integrated risk management is to apply while setting priorities between different demands of protection. In addition to the preparedness, also responsive measures have to be taken to improve the management of an event and the post-earthquake recondition and reconstruction. Infrastructure systems play an important role during this response and recovery phase.

Based on the long-term strategy of the Swiss federal council concerning the earthquake mitigation of infrastructures, the following aspects (not concluding) are relevant for the FOEN to meet the objective of a Swiss-wide earthquake risk reduction for infrastructure systems:

- Systematic studies of the vulnerability
- Definition of need for action (sector specific and overlapping)
- Development of practical and standardized mitigation instruments
- Compilation of criteria and procedures for authorisation processes (state, canton and communes)
- Intensification of the supervision
- Investigation of the potential of organisational measures
- Development of communication and sensitization concepts

To reach an appropriated seismic safety of infrastructures in Switzerland there is need for action on different levels. On one hand there is the system level of each infrastructure sector with the goal to analyse the seismic safety and implement technical and organisational measures to improve the safety. On the other hand there is the component level with the goal to improve those elements that cause over and over damages due to earthquakes in all kinds of systems, like the safety of buildings or the non structural elements that are vital for the functionality of infrastructures. Finally there is also a need to develop more fundamentals, for example to convey the awareness of earthquakes. Norms and technical guidelines have to be developed or to be adapted to the specificities of sectors and concretely to be applied. Furthermore the education and the research must be encouraged.

Basically the targets to reach regarding earthquake mitigation are the same for all infrastructure systems, within or outside the competence field of the state. The aspect of responsibility and authority competence has no influence on the general method to examine infrastructures, but on the concrete implementation of measures and their financing.

3. INTEGRAL SEISMIC PREVENTION PROCESS FOR INFRASTRUCUTRES

The Coordination Centre of the FOEN has analysed the infrastructures with always the same method that accords with the integral prevention process (see Figure 1). The key for a successful study and a broad acceptance is to involve from the start all the relevant stakeholders of a sector, including authorisation authorities, umbrella organisations, representative partners of the industry and experts. Those work groups can co-decide the approach and judge the efficiency and practicability of measures. Because of the difficulty to define protection goals and due to the complexity of the responsibilities the focus lies at the start of this cyclic process on the following steps that are relevant for earthquake mitigation.

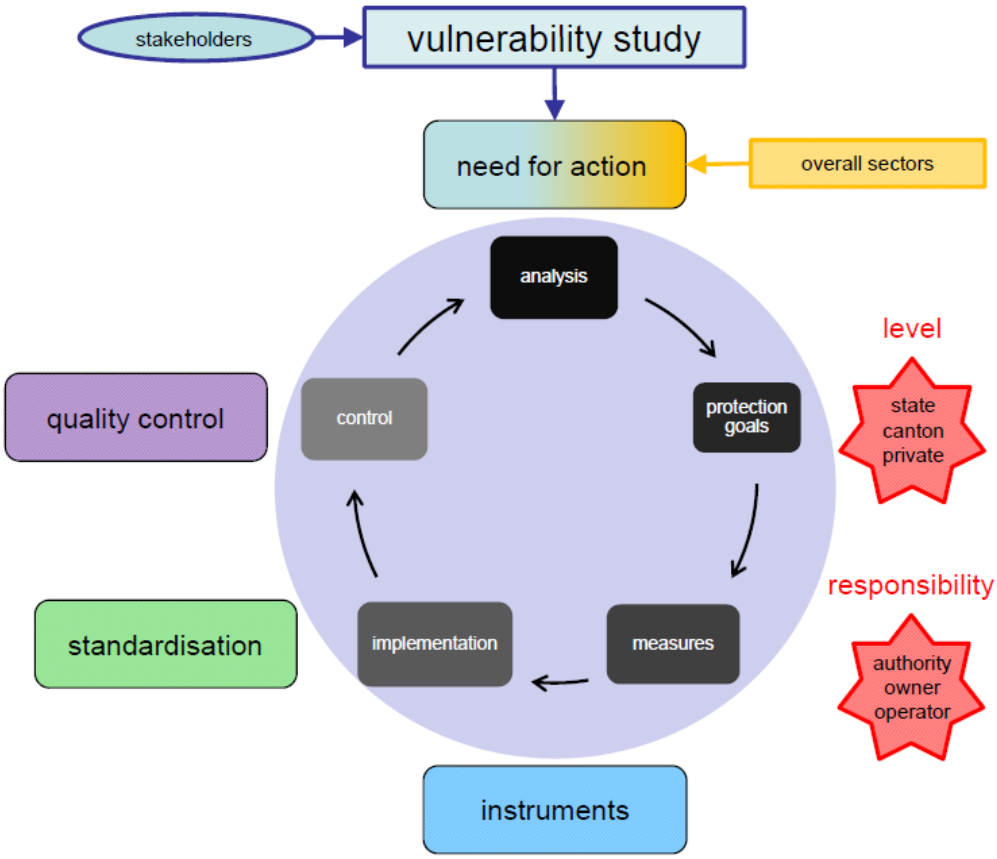

Figure 1. Integral seismic prevention process for infrastructures in Switzerland

3.1. Vulnerability studies

The first step of the process is a vulnerability study. The relevant information about the infrastructure system must be brought together as well as the specific construction practice and the guidelines applied in Switzerland. Based also on the international experiences after earthquakes, the seismic vulnerability has to be evaluated and the risk concentrations identified. In addition to technical aspects also operational and organisational aspects must be investigated, as for example the emergency response or the relevancy of interdependencies.

3.2. Definition of need for action

The need for action is based on the sector specific need defined in the vulnerability study and on sector overlapping aspects that are known as weak points in most infrastructures. Those aspects concern for example the seismic safety of operational buildings, of non structural elements, devices and installations or the response management of en event. Such weak points are known for affecting the functionality of an overall system after an earthquake.

Because of the complexity of net structures, the interlaced responsibilities within a sector and the interdependencies between infrastructure sectors, the difficulty lies not in the definition of need for action but more in the assignation of the responsibility to implement concrete measures and at the end to finance them.

3.3. Compilation of practical instruments

With the goal to implement the proposed measures in the practice, standardised instruments must be compiled. Those practical instruments have to be introduced by the authorisation authorities as well as by private suppliers to reduce the seismic risk of existing facilities and also to avoid a risk increase by non seismic new facilities.

3.4. Implementation and quality management

The awareness of earthquake is mostly missing in Switzerland so that standardised proceedings are needed to implement seismic measures and also to control their quality and effect on the seismic risk reduction. Those risk oriented quality controls must be introduced on all levels, from national authorisation authorities to private business internal processes. Therefore the responsibilities have to be clearly defined. The integral seismic prevention process has to be carried on continuously so that control work will reduce with rising awareness and decreasing risk.

4. ACTUEL SITUATION AND PRACTICAL IMPLEMENTATION

According to the priorities set by the federal earthquake risk mitigation program, an inventory of the bridges of national roads has been achieved. About 19% of the more than 4’000 bridges have been prioritised for deeper investigations that are still running. At the moment, only a little minority of bridges needs earthquake retrofitting measures, mostly at the longitudinal bearings. For the following sectors where federal authorities have authorisation competences vulnerability studies have been achieved and published: Electric power utility, Railway and Gas utility. Considered as relevant in a seismic point of view but supervised only on cantonal level, the waste water utility has also been investigated. For the buildings of airports instruments are in order to be implemented to control the seismic standards in the practice.

Overall a publication will come out in 2012 with the purpose to raise the awareness of seismic risk to the user and suppliers of infrastructures in Switzerland and to the authorities on all levels. The own responsibility should be enhanced by educating as well as the implementation of efficient measures in practice should be encouraged. The focus concentrates on convincing and proportionate measures that are efficient to reduce well known and common damages to infrastructure systems.

4.1. Electrical power distribution

The Swiss electricity market is partly liberalised since 2009 and strongly fragmented with over 800 network operators. Until the end of 2012 the high-voltage power grid (6700 km) will go over to a national operator of the Swiss transmission system, called Swissgrid. The reorganisation results in the separation of electricity generation, trading and distribution and transmission. The Federal Inspectorate for Heavy Current Installations (ESTI) is competent for the issue of authorisations, for inspections and supervisions.

Since 2008 the electrical power utility has been investigated by studies and pilot projects (see [5] and [6]).The technical findings have been integrated in a technical guideline of the ESTI “Seismic safety of the electrical power distribution in Switzerland” that will be in force in 2012 (see [7]). Furthermore the findings will be used to sensibilise the electrical branch at an expert conference hold in September 2012.

For the supply security of the society regarding the seismic hazard in Switzerland, the focus lies on the distribution and not on the generation of power, mainly due to the geographical situation of Switzerland in Europe and the dimension of the affected area by an expected earthquake. According to the findings of the study and partially based on experiences abroad, the biggest damages at the electrical power distribution supply in case of earthquakes occur to outdoor type substations. The higher the voltage level, the higher the vulnerability of substations. Damages are expected on power transformers, especially on the bushings, as well as on high voltage equipments. Today in Switzerland there is also a problem with the cable connections that are too tight. The lack of slack in connections results in the fact that the equipments connected cannot oscillate independently, so that big interaction forces appear that cause the rupture of equipments, especially of porcelain busses. Also secondary systems, such as emergency power batteries or control units, present important weak points so that they fail even in case of moderate earthquakes and can cause a black-out. The implementation of preventive measures in those fields should lead to an increasing supply safety in case of an earthquake. If those measures are taken consequently for new facilities and while renovating existing substations, the additional costs for reducing the seismic risk are extremely low in comparison to the total costs of a project or to the costs of business interruption.

One of the main problems lies in the missing anchorage of big transformers against lifting. The risk for transformers to topple over depends extremely on their resonance frequencies. To this topic contradictory information can be found in literature so that recordings were made on typical transformers for Switzerland. In those pilot projects the existing slacks between equipments were also measured to specify the practice in Switzerland.

In the new ESTI-guideline the requirements are graduated in function of the seismic hazard zones and the voltage level. In order to guarantee a broad acceptance of the guideline and to avoid disproportionate measures, the requirements are limited to new facilities and electrical components. For existing facilities that are not yet renovated, the requirements have simply the state of recommendations. The following table of the ESTI-guideline defines the field of application in function of the voltage-level.

Table 1. Field of application of the new ESTI-guideline

Seismic safety of	**Voltage-level**
Transformers	All voltage-levels
Electrical equipments	Voltage-level of 220 kV and higher
Cable connections (slack)	Voltage-level of 220 kV and higher
Buildings of the secondary technique	All voltage-levels
Power distribution equipments in racks	All voltage-levels
Secondary systems and other subcomponents	All voltage-levels
Overhead lines	Voltage-level of 220 kV and higher

The requirements of the ESTI-guideline for substations focus on the following aspects:

- Seismic safety of **transformers**:
  Subject to the seismic hazard zone and in function to the slenderness ration of the transformers, seismic standards (according to IEC) are requested as well as a verification of the anchorage concerning the traction and shear forces. The resonance frequency plays an important role and should be determined more precisely. If not, the maximal spectral response acceleration should be applied.
- Seismic safety of **high-voltage equipments**:
  Subject to the seismic hazard zone, seismic standards (according to IEC) are requested as well as a verification of the anchorage concerning the traction and shear forces. The resonance frequency

plays also an important role.

- Seismic design of **cable connections**:
  In function of the resonance frequencies of the two connected components, the seismic hazard zone and the soil characteristics, the required slack is given.
- Seismic safety of **buildings**:
  For all voltage-levels new buildings must be designed according to the building codes. For existing buildings recommendations are made for the proportionate rehabilitation.
- Seismic safety of **secondary systems**, equipments in racks and other subcomponents:
  For all voltage-levels and all seismic hazard zones, it is required to secure those components, such as control racks, backup power batteries and units or such as double floors, divider walls, etc against earthquake.

For important existing substations a seismic rehabilitation is recommended if necessary and proportionate (that is mostly the case for secondary systems and subcomponents or if the regional supply security can be put at risk and no renovation is planned in the next 20 years. The identification of important substations and their voluntary rehabilitation are in the responsibility of the operator.

The EST-guideline is in force 2012. It is now extremely important to communicate in a proper order the requirements and the application field as well as the main objective of this work. In addition the control has to become a standard to guarantee a correct and concrete implementation in the practise. However the federal authority must be flexible enough to find solutions for special projects and also never forget the main target, which is trying to reduce the seismic risk on a country wide level to increase the distribution safety of electrical power even after an earthquake.

4.2. Waste water system

The waste water system plays an important role in our society for people and the environment to preserve health and to protect groundwater. The operators in Switzerland have never considered the seismic risk while building and operating the waste water system, so a vulnerability study as well as pilot projects has been achieved (see [8]). Basically the waste water supplies are conceded on canton level. The cantons are also in charge of the implementation of the law in the field of water protection and responsible in case of a disaster. Nevertheless a recommendation should be published in 2012 based on the findings of the study to help the more than 900 waste water operators in Switzerland and the cantonal departments to implement measure to reduce the seismic risk.

The concrete results of the study are three instruments that have the objective to evaluate and increase the seismic safety of new and existing waste water facilities:

- **Recommendations**:
  The recommendation should be published by the umbrella organisation of the operators and introduced at conference so that it becomes as soon as possible a state-of-the-art document in the Swiss branch of waste water. In addition to concrete preventive measures the recommendation handles also with aspects of preparation and intervention after an earthquake. Those points are important to come back as fast as possible to a normal business. Setting priorities during reconstruction can be very important to avoid for example an increasing contamination of potable water.
- **Relevancy assessment**:
  The missing competence of the federal government in the field of waste water does not allow using the relevancy assessment instrument to prioritise measures on a national level. Nevertheless this instrument can be used be the cantons to prioritise or even by single operators. It allows identifying those components of the net structure the potentially lead in case of an earthquake to important consequential damages for the environment and the potable water supply.

- **Inspection concept**:
  Basically simple and efficient measures should be implemented without huge concept. But for an efficient assessment concept a deeper inspection of a waste water system is necessary. The proposed concept is composed of 5 steps: Analysis of the function, Analysis of the relevancy, raw assessment, detailed assessment, concept of measures.

To increase the seismic safety of the waste water system in Switzerland in the long term, awareness rising as well as education is needed. In addition to the operators and owners, the cantonal departments must be informed and have to introduce control mechanism in the permit delivery procedures.

5. PROBLEMS AND SUCCESS CONDITIONS

Infrastructure systems have a big relevancy in our society and experiences and studies show that they are really vulnerable against earthquake, even in Switzerland. The net structures of the systems, as well as their complexity and the interdependencies aggravate the problem. So it is also difficult to prioritise in an objective way measures to reduce the seismic risk in Switzerland. The complex distribution of responsibilities between the federal and the cantonal level, as well as between authorities, owners and operators makes it even more difficult, as the financing of measures becomes unclear sometimes.

Despite those problems, efficient and proportionate measures are well known and it is time to implement them, as well for existing facilities as of course for new ones. Because of the nearly non existing awareness of the seismic risk, it is important, at least at the beginning, to control effectively the implementation of measures. Involving all stakeholders of a branch from the beginning is also an important key to achieve the target of earthquake mitigation.

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