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IS THE RESIDUAL RISK RELATED TO THE SWISS SEISMIC CODE PROVISIONS ACCEPTABLE?

Blaise DUVERNAY[1], Ehrfried KÖLZ[2], Navid JAMALI[3], Clotaire MICHEL[4]

ABSTRACT

This paper illustrates the results of residual risk computations related to the application of the current code provisions for seismic design and retrofit in Switzerland and discusses the acceptability of the code provisions and the potential for optimization. Individual risk (annual probability of death of an individual), probability of exceedance of different damage states and financial risk related to direct damage to buildings are used as metrics for this discussion.

For new buildings, the main conclusion is that a design based on a 475 year return period seismic action is sufficient regarding the safety of individuals. Computations show that an annual probability of death (unit casualty risk) in the order of 10^{-6} is generally achieved. However, the seismic provisions may not be optimal regarding the financial risk related to the cost of damage and downtime. Moreover it seems that the individual risk related to earthquakes is about one order of magnitude higher compared to those stemming from other hazards like wind, snow or overloading.

For existing buildings the main conclusion is that the minimum compliance factors for structural safety in the pre-standard SIA 2018 and the new code SIA 269/8 is sufficient regarding the safety of individuals (annual probability of death less than of 10^{-5}). Cost benefit analyses show that retrofitting buildings to a higher compliance would be in many cases economically unjustified if one considers only the risk reduction to people and building value.

From a societal standpoint, it can be argued that code provisions should be more stringent in densely populated areas to account for risk concentration and more severe indirect damages. It can also be argued that cost-benefit analysis should also consider societal costs related to a large number of people needing assistance after an event, which is usually the case for earthquakes. Such ideas are worth to be investigated but are still far away from being implementable as performance objectives in buildings codes.

Keywords: seismic design; residual risk; swisscodes; acceptance.

1. INTRODUCTION

In the introduction, published recommendations for safety goals and protection objectives against natural hazards, safety objectives and seismic provisions of buildings codes in Switzerland are introduced and their interdependence is briefly discussed.

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[1]Federal office for the environment, Bern, Switzerland, blaise.duvernay@bafu.admin.ch
[2]Risk&Safety AG, Aarau, Switzerland, koelz@risksafety.ch
[3]Risk&Safety AG, Aarau, Switzerland, jamali@risksafety.ch
[4]Risk&Safety AG, Aarau, Switzerland, michel@risksafety.ch

1.1 Safety goals and protection objectives against natural hazards

In its document "Safety Level for Natural Hazards" (PLANAT, 2013), the National Platform for Natural Hazards, gives recommendations for a uniform definition of safety level and protection objectives as well as for the formulation of safety goals. These recommendations, which are not legally binding, are primarily aimed at the Federal Council and the Department for Energy, Communication, Transport, Environment and Communication (DETEC) as its commissioning bodies. They are also aimed at those who are responsible for the implementation of an integrated risk management against natural hazards. PLANAT recommends that the following safety goals be used as long-term targets for the protected objects:

- The average risk of death for **human beings** is not significantly increased by natural hazards. The annual risk of being killed as a result of natural hazards is significantly lower than the average probability of death for the age group with the lowest mortality rate in Switzerland.
- **Buildings** have to provide a high level of protection to persons and their movable goods. They have to be resistant and should not pose any threat to persons and other material assets. The residual risks to persons and material assets are acceptable to the risk carriers.
- The risk to **infrastructure, economically important assets and essential natural resources for livelihood** is so low that the continued existence of the society is guaranteed today and for generations to come. Vital goods and services may only be disrupted simultaneously in large parts of Switzerland for short periods of time.
- **Cultural goods** are protected from natural hazards to ensure that their cultural value is conserved permanently.

The PLANAT recommendations are very general and do not include specific numerical values. The idea is that these safety goals and specific protection objectives should be further concretized by the relevant stakeholders. The first two safety goals which are focused on the protection of individuals and material assets are the most relevant for the Swiss society of engineers and architects (SIA) as it is the primary stakeholder defining load cases and design prescriptions (protection objectives) for civil engineering structures. Regarding the safety of individuals, a well admitted acceptance threshold for the annual risk of being killed as a result of natural hazards is 10^{-5} (PLANAT, 2015). This value has already been explicitly used as a reference in the development of seismic prescriptions for existing buildings in Switzerland in 2004. This value is used as a reference for the safety of individuals in this paper. Until now, no explicit threshold value regarding the acceptable residual risk for material assets (buildings and contents) has been formulated in Switzerland. In this paper, we focus on ordinary buildings, which are the primary source of earthquake risk. The third and fourth safety goals are not discussed further in this paper.

1.2 Performance objectives in building codes

Building codes are calibrated so that structural design can reach a consistent level of reliability without doing a detailed reliability analysis for each design (JCSS, 2008). Codes specify how to determine characteristic loads and material parameters and provide partial design factors as well as further requirements (conceptual or constructive measures) that the designer must satisfy. With this, an appropriate and economical safety for individuals and robustness for structures should be achieved. Further prerequisites are that the uncertainty in the characterization of the action, the structural modeling and the determination of the effects of the action are assessed correctly and that appropriate quality insurance measures are taken during the design, execution, use and maintenance of the structure.

The target reliability in building codes is expressed by a reliability index β. Reliability indices are typically given for structural safety and serviceability. They can be transformed into a yearly probability of exceedance of the corresponding limit state. These requirements are valid for individual structural members. Reliability indices for the whole structural system are not explicitly provided, but measures must be implemented so that the consequences of an individual structural member reaching failure remain limited (no progressive catastrophic failure). As an example, the targeted reliability for normal habitation and office buildings in Eurocode EN1990:2002 "Eurocode: basis for structural design" (EN 1990, 2002) can be formulated as follows. These are also valid in the framework of the Swiss building codes.

- All members of the structure have a reliability index β of 4.7 for structural safety and have therefore a probability of failure lower than 10^{-6} per year.
- All members of the structure have a reliability index β of 2.9 for serviceability and have therefore a probability of exceeding this limit state lower than 2 10^{-3} per year.

These reference values are used in this paper to check whether the seismic design of ordinary buildings according to the Swiss building codes fulfills these reliability requirements. For this, not meeting the structural safety requirement is interpreted as the building reaching a damage grade 3 according to the European Macroseismic Scale EMS98 (Table 1). Not meeting the serviceability requirement is interpreted as the structure reaching damage grade 1.

Table 1. EMS98 Damage classification (Grünthal et al., 1998).

Damage grade	Masonry buildings	Reinforced concrete buildings
Damage grade 1: Negligible to slight damage (no structural damage, slight non-structural damage)	Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases.	Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills.
Damage grade 2: Moderate damage (slight structural damage, moderate non-structural damage)	Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.	Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.
Damage grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)	Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls).	Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of concrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels.
Damage grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage)	Serious failure of walls; partial structural failure of roofs and floors.	Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor.
Damage grade 5: Destruction	Total or near total collapse.	Collapse of ground floor or parts (e. g. wings) of buildings.

Eurocode EN1990:2002 further gives indications and target values to adapt the reliability index depending on the consequences of failure or loss of serviceability of a construction. The exact underlying objectives are not specified. Methods to define reliability indices based on the relative cost of measures and on the consequences of failure are discussed in JCSS (2008) and in Narasimhan (2012). For high costs and large consequences, it is for example suggested that the yearly probability of failure (reaching or exceeding the limit state for structural safety) could be set as high as 10^{-4} instead of 10^{-6}. This proposed threshold value of 10^{-4} per year is of interest for existing buildings, where no commensurate retrofitting measures can be found to increase the seismic safety.

1.3 Seismic code provisions for new buildings

1.3.1 The building code SIA 261

For new structures, the seismic provisions of the Swiss building codes (SIA 261, 2014) are largely in line with the provisions of the current Eurocode 8, part 1 (EN1998-1, 2004). The type 1 elastic design spectra for a return period of 475 years and importance factors of 1.0, 1.2 and 1.4 depending on the importance class of the structure define the seismic design loads for structural safety design. A verification of serviceability is only required for the highest importance class (importance class III).

1.3.2 The 475 year return period for the seismic action and what's behind it

The use of the seismic action for a return period of 475 years as a basis for the seismic design is common to many modern building codes. This reference value has been originally selected for building codes in regions of high seismicity, such as California. The complex historical development and rationale behind the choice of a return period of 500 years is described in chapter 11 of Scawthorn et al. (2002). BSSC (1997), which was an accepted consensus and basis for modern seismic provisions in the US, recommended to use a maximum considered earthquake (MCE) ground shaking for a return period of 2'500 years. This level of seismic hazard was selected to be representative for a maximum, or near maximum credible event and for strong historical events. Close to active faults with a high activity rate, the MCE ground shaking can be replaced by deterministic values from characteristic earthquake scenarios. The targeted performance objective in BSSC (1997) is a conditional collapse probability for buildings designed according to code of at most 1% for the MCE seismic action (collapse prevention objective, interpreted here as a conditional probability of at most 1% of reaching or exceeding damage grade 4 according to the EMS98 (table 1)). Taking into account the conservativeness used for the design of structural members in building codes, it was set that designing with 2/3 of the 2'500 year return period seismic action would satisfy the collapse prevention objective. It was observed that 2/3 of the 2'500 year seismic action corresponded to the 500-year return period seismic action for the hazard data available at the time. This explains the choice to use 500 years as the return period to define the seismic action in modern building codes. This choice has then been further adopted in zones of low to moderate seismicity without really testing if the performance objective behind it was still met. In this respect, hazard curves in regions of low to moderate seismicity show that 2/3 of the 2'500 year return period seismic action corresponds rather to a seismic action with a return period of approximately 1'000 years instead of 500. It can be therefore expected that the safety level of structures using the 500 year return period seismic action for design will be lower in zones of low to moderate seismicity than in zones of high seismicity, all other things being kept equal. Beside the shape of the hazard curves, the uncertainty in the structural fragility influences significantly the safety level. For this reason, the concept of risk-targeted hazard map has recently emerged. For instance, Silva et al. (2016) proposed a map of Europe of the collapse probability of new seismically designed buildings. It confirms that buildings designed in higher seismicity areas are safer.

1.3.3 Declarative protection objectives of the Eurocode 8

Eurocode 8 part 1 (EN1998-1, 2004) contains declarative protection objectives summarized as follows:

- **No collapse requirement.** The structure shall be designed and constructed to withstand the design seismic action without local or global collapse, thus retaining its structural integrity and a residual load bearing capacity after the seismic events. The associated recommended return period for the seismic action to be considered is 475 years.
- **Damage limitation requirement.** The structure shall be designed and constructed to withstand a seismic action having a larger probability of occurrence than the design seismic action, without the occurrence of damage and the associated limitations of use, the costs of which would be disproportionately high in comparison with the costs of the structure itself. The associated recommended return period for the seismic action to be considered is 95 years.

Eurocode 8 doesn't provide recommendation values for the target reliabilities. These have to be decided by the national authorities, which was, to the knowledge of the authors, not explicitly done in the case of SIA building codes. The non-collapse requirement is interpreted in this study as "the structure should have a low probability (1%) to reach damage grade 4 according to EMS98 (table 1) after the occurrence of the design seismic action.

1.4 Seismic code provisions for existing buildings

The pre-standard SIA 2018 (SIA, 2004) for the verification of the seismic safety of existing buildings was published in 2004 and replaced in December 2017 by the new building code SIA 269/8 "Existing structures - earthquakes" (SIA, 2017). This new code uses the main principles of the pre-standard SIA 2018 and it is applicable to a wider range of existing structures, like earth- and retaining structures.
The first central concept of SIA 269/8 is the **compliance factor α_{eff}** which indicates the degree of compliance of an existing structure with the requirements for new structures. For construction works class I (common structures) and II (structures with high occupancy, or with high consequences in case of collapse), the minimum compliance factor α_{min} is 0,25. For construction works class III as well as for school buildings and constructions with an important infrastructure function, the minimum compliance factor α_{min} is 0,40. Below the minimum compliance factor of 0.25, the safety of individuals is deemed unacceptable with an annual probability of death exceeding 10^{-5} (see also section 2.2).

The second central concept is the **recommendation of measures**. Three cases are distinguished depending on the compliance factor of an existing structure (see also Figure 1):

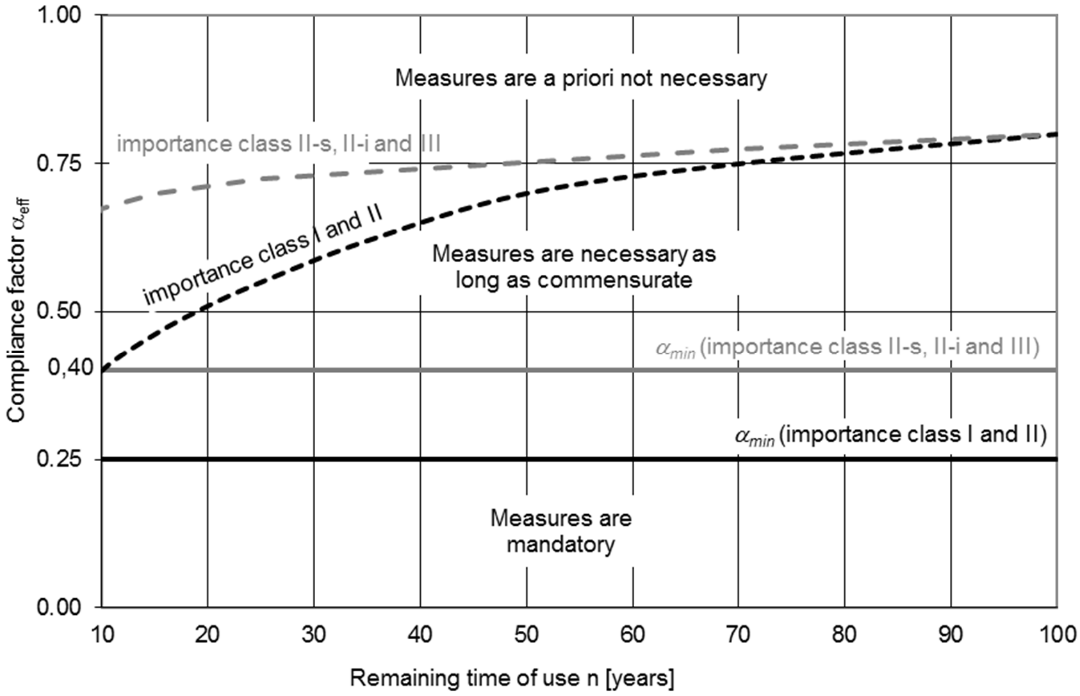

Figure 1: Recommendations of measures according to the new SIA building code 269/8.

1. If the compliance factor α_{eff} is under the threshold value of α_{min}, retrofit measures are necessary in order to reach a compliance factor after intervention (α_{int}) at least equal to α_{min}.
2. If the compliance factor α_{eff} is above α_{min} but below the dashed curves in Figure 1, then retrofitting must be implemented as long as the related measures are *commensurate*. The objective is to reach a compliance factor of 1,0. If this is not possible, measures must be implemented up until the limit of commensurability. If no commensurate measures can be found then the existing state can be accepted.
3. If the compliance factor α_{eff} is above the dashed line in Figure 1, the existing state is acceptable as it is probably impossible to find commensurate measures.

The third central concept is the **commensurability of measures**. In SIA 269/8 the criterion used is the efficiency of measures EF_M, which is the ratio between the risk reduction in Swiss francs per year and the annualized cost of measures computed with a discounting factor of 2 % over the remaining time of use. In SIA 269/8, risk reduction can be explicitly computed for casualty risk (figure 2), risk of direct damage to the building and its content (Figure 3), business interruption and loss of infrastructure function. Using figure 2, the casualty risk is computed by multiplying the risk factor for individuals by the average number of people in the building and a value of 10 million Swiss francs per life saved. Using figure 3, the annualized risk from direct damage to the construction is calculated as the multiplication of the risk factor BRF by the value of the construction.

2. PROBABILISTIC RISK FOR BENCHMARK BUILDINGS AND DERIVED RISK CURVES

2.1 Context

As a support to the issuance of the new building code SIA 269/8 and in the interest of providing better tools for the probabilistic seismic risk computation for existing buildings in Switzerland, the Federal Office for the Environment (FOEN) initiated a research project with the following objectives:

- Provide a consistent set of probabilistic hazard data in EMS-Intensity (empirical approach) and spectral acceleration values (mechanical approach) for 4 sites covering the range of seismic hazard in Switzerland.
- Develop fragility functions for 5 existing benchmark buildings, including uncertainties. Develop fragility functions for 2 retrofitted buildings from the original set of 5 buildings.
- Prepare a reusable documented computational framework for the probabilistic risk quantification using an empirical approach (based on macroseismic intensity) and a mechanical approach (based on spectral acceleration).
- Obtain verification data for the casualty risk curve in the pre-standard SIA 2018 (figure 2) and data for the risk curve for property damage in the new building SIA 269/8 (figure 3).

A synthesis of the results of these studies (Jamali et al., 2015; Karbassi et al. 2015) is used in this paper to assess and discuss the residual risk related to the Swiss seismic code provisions. Although the risk studies were performed for existing buildings that were not designed according to the seismic provisions of the Swiss building codes, the results can be extrapolated up to a compliance factor of 1, which is used as proxy for code compliant buildings. The results presented in section 2 and the related discussions in section 3 are focused on results that are valid for a force-based design or verification of buildings. For a discussion of the limitations and specific issues related to the probabilistic computation of the seismic risk for the benchmark buildings, the reader is referred to Jamali et al. (2015).

2.2 Casualty risk

Figure 2 shows the results of the computations of the risk factor to individuals (PRF, annual probability of death of an individual) for the 5 benchmark existing buildings and 2 retrofitted buildings in 4 locations in Switzerland for both mechanical and empirical approaches (Jamali et al., 2015). They are compared to the risk curves from the building code SIA 269/8 and the pre-standard SIA 2018 that relate the compliance factor α_{eff} of a building with the PRF.

The large scatter in the results in Figure 2 indicates a large uncertainty in the probabilistic seismic risk computations and a far from perfect correlation between the compliance factor and the casualty risk. The results nevertheless confirm that a minimum compliance factor α_{min} of 0.25 is an adequate threshold between cases with an unacceptable, versus acceptable safety for individuals (threshold value for PRF of 10^{-5}). The exact form of the selected risk curve in SIA 269/8 is based on a rather qualitative fitting through the data set. For logical consistency with the declared safety objective and selected value for α_{min} the curve passes through the point (α_{eff} = 0.25; PRF = 10^{-5}). Furthermore it is selected so that the risk reduction for people with the increase of the compliance factor is somewhat higher than what it would be the case when using a best fit curve through the dataset. This choice is motivated by the fact that the curve should be on the "safe side" regarding the choice of investing to reduce risk to individuals in the face of the large uncertainties at hand.

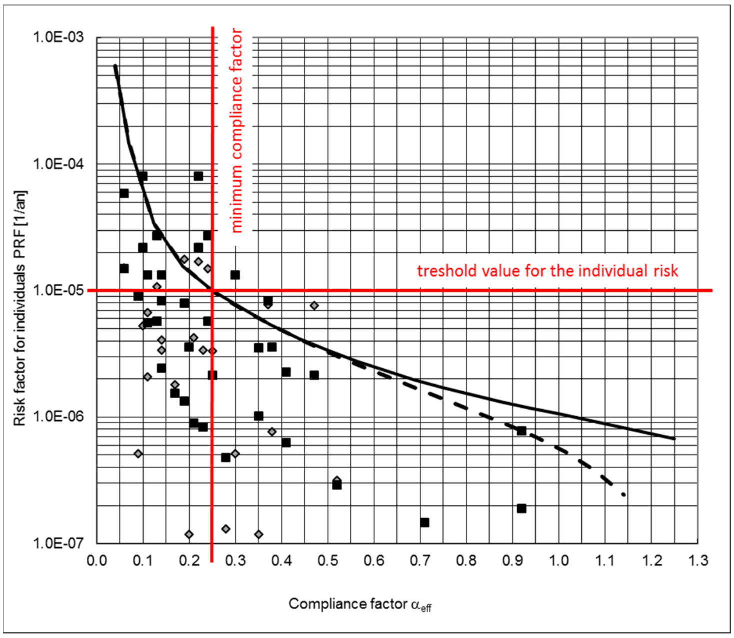

Figure 2: Individual risk curves in the building code SIA 269/8 (continuous) and in the pre-standard SIA 2018 (dashed) and results of the PRF computations of Jamali et al. (2015) (squares: mechanical approach; diamonds: empirical approach).

2.3 Risk related to the direct property damage

Figure 3 presents the results of the computations of the unit property loss risk (BRF, annual direct structural and non-structural loss) for 5 benchmark existing buildings and 2 retrofitted buildings in 4 locations in Switzerland for both mechanical and empirical approaches (Jamali et al., 2015). It is compared to the risk curve from the building code SIA 269/8 relating the compliance factor α_{eff} of a building to the BRF.

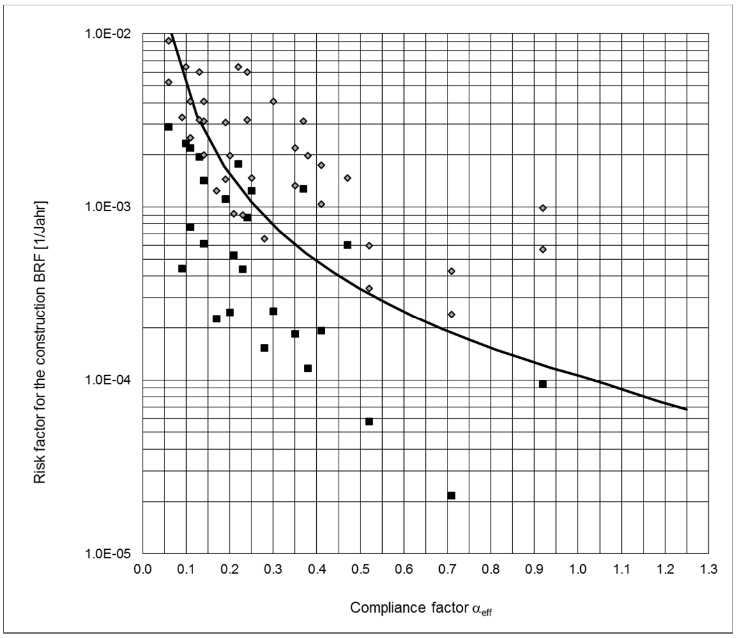

Figure 3: Risk curve in the building code SIA 269/8 and results of the computations of unit property loss of Jamali et al. (2015) (squares: mechanical approach; diamonds: empirical approach).

The results show again a large dispersion for the same reasons as stated in section 2.2. A systematic difference is observed between the results from the empirical approach and the mechanical approach, which is representative of a large epistemic uncertainty. The form of the selected risk curve in SIA 269/8 is based on a best fit approach through the data set.

2.4 Probability of exceedance of different damage grades

In Figures 4 and 5, different relevant probability of exceedance of EMS98 damage grades (table 1) are presented. The results show again a large scatter with a systematic difference between the empirical and the mechanical approaches. Most of the usable data is for a compliance factor lower than 0.5. Possible ranges of exceedance probabilities for a compliance factor of 1 are estimated through a regression of the dataset for the empirical and mechanical approaches.

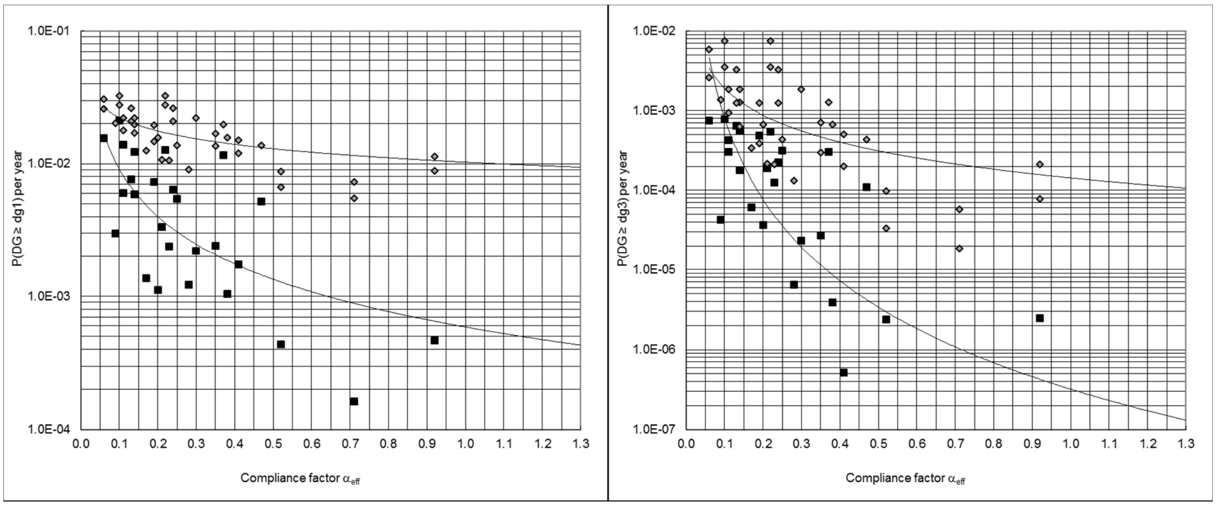

Figure 4: Annual probability of damage (*i.e.* exceeding damage grade 1) (left) and probability of reaching damage grade 3 (right) for 5 benchmark existing buildings and 2 retrofitted buildings in 4 locations in Switzerland as a function of compliance factor α_{eff} (squares: mechanical approach; diamonds: empirical approach) (Jamali et al., 2015).

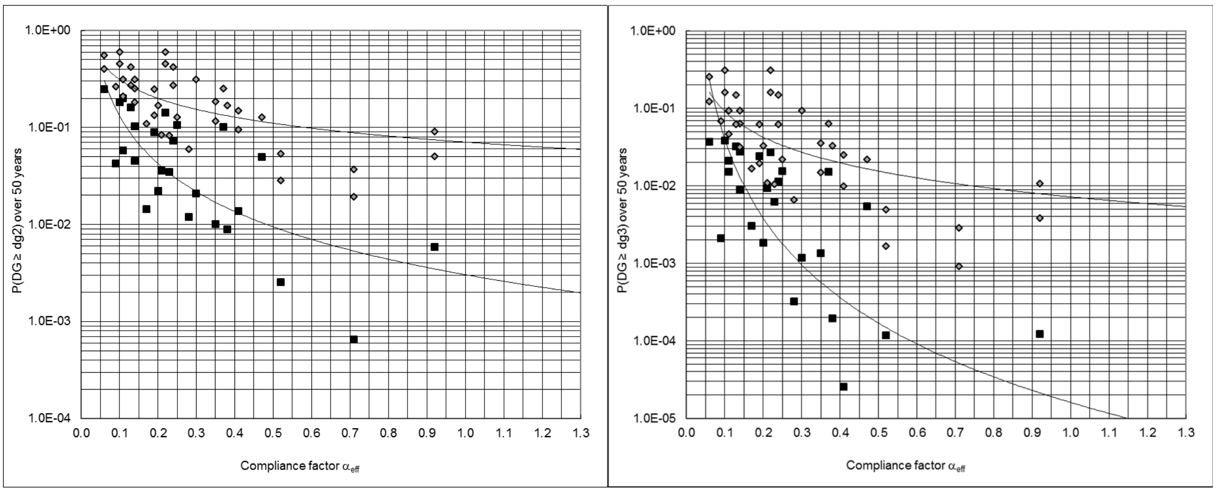

Figure 5: Probability of exceedance of damage grade 2 (left) and 3 (right) over a period of 50 years for 5 benchmark existing buildings and 2 retrofitted buildings in 4 locations in Switzerland as a function of compliance factor α_{eff} (squares: mechanical approach; diamonds: empirical approach) (Jamali et al., 2015).

3. DISCUSSION OF THE ACCEPTABILITY OF THE RESIDUAL RISK

3.1 Individual risk to people

For new buildings, this study shows that a design based on a 475 year return period seismic action for a zone of low to moderate seismicity like Switzerland leads to an annual probability of death in the order of 10^{-6}, which is an order of magnitude lower than the accepted threshold value for the protection of individuals against natural hazards in Switzerland. Looking at figure 2, it can be argued that further reducing the human risk by raising the seismic provisions for new buildings might be disproportionate if one only considers the risk reduction to people. This would need to be further investigated.

For existing buildings, the minimum compliance factors for structural safety in SIA 269/8 has been calibrated by design so that it leads lead to an annual probability of death of 10^{-5}, which is the accepted threshold value for the protection of individuals against natural hazards in Switzerland. Experience shows that this risk can be further reduced by commensurate measures in buildings with high occupancy (Wenk, 2008).

3.2 Financial risk due to the direct structural and non-structural damage

Using figure 3, which is the summary of the risk computations performed by Jamali et al. (2015), it can be seen that, for a compliance factor of 1.0 (code compliant new buildings), the annualized property risk should be in the order of 10^{-4} multiplied by the building value. For a building value of 1 million Swiss francs, this amounts to a financial risk linked to the direct damage of the building of 100 Swiss francs per year. There is no explicit threshold value for such a risk in Switzerland so that its acceptability cannot be directly assessed. A good indicator regarding the acceptability of the residual financial risk is that private insurance companies are willing to insure properties with such risk levels and that premiums tailored to the risk level of code compliant buildings would be relatively cheap and thus acceptable from the standpoint of an owner. As a further point of comparison, current private seismic insurance policies for existing buildings (regardless of code compliance) have yearly premiums (with a deductible between 5 and 10% of the building value) that are typically in the range of 250 to 800 Swiss francs for a building value of 1 million Swiss francs.

More relevant from an owner's perspective would be the yearly probability (or the probability over a period of 50 years) to lose a substantial amount of the building value, leading to very serious financial problems if he is not insured. If we consider this situation to be the probability of reaching damage grade 3, then, for a code compliant building, the yearly probability of a so-called financial ruin would be in the order of 0.1% over a period of 50 years (see figure 5). Here again, the acceptability of such a probability cannot be discussed as threshold values are not formulated for such risks.

For existing buildings, it can be seen in figure 3 that for the minimum compliance factor of 0.25 (or 25%), the risk index for building damage is an order of magnitude higher. If a majority of existing buildings were to be at this low level of seismic safety, then the risk would be difficult to insure. Premiums would be very high and insurances would probably not be willing to have a high market penetration because of the risk concentration.

3.3 Consistency with the reliability requirements of the building codes

A regression of the data in figure 4 left leads to an expected range for $P(DG \geq dg3 \mid \alpha_{eff} = 1.0)$ between $5 \cdot 10^{-7}$ and 10^{-4} per year. This range is mostly above the value of 10^{-6} per year required for the reliability for structural safety according to Eurocode EN1990:2002 "Eurocode: basis for structural design". Even if one considers $P(DG \geq dg4 \mid \alpha_{eff} = 1.0)$ per year to be a more appropriate indicator to assess the reliability for structural safety, the results are still partly an order of magnitude higher than the threshold value of 10^{-6} per year.

A regression of the data in figure 4 right leads to an expected range for $P(DG \geq dg1 \mid \alpha_{eff} = 1.0)$ between $5 \cdot 10^{-4}$ and 10^{-2} per year. This range is partly above the value of $2 \cdot 10^{-3}$ per year required for the reliability for serviceability according to Eurocode EN1990:2002. If one considers $P(DG \geq dg2 \mid \alpha_{eff} = 1.0)$ per year to be a more appropriate indicator to assess the reliability for serviceability, then in this case, the results would be lower than the threshold value of 2.10^{-3} per year and the criterion of EN1990:2002 would be fulfilled.

These comparisons tend to show that seismic design according to the Swiss building codes are probably not meeting the reliability requirements for structural safety and serviceability according to the Eurocodes. The discrepancy seems greater for structural safety than for serviceability. It can be supposed that this finding is in general valid for other countries using Eurocodes. Building code committees need to decide if lower reliability indices are acceptable for rare accidental load cases like earthquakes or not.

3.4 Consistency with the general expectations of building owners

Building owners or their representatives are usually unaware of the nature of the protection objectives for seismic design in the building codes. One frequent expectation is that no damage should occur to their structure in case of an earthquake as it is designed according to the codes. As figure 5 is showing the probability of having a substantial damage to a building over a period of 50 years is not negligible, even if the building has a compliance factor of 1.0 (proxy for a new code compliant building).
If one interprets damage grade 2 according to the EMS as being a threshold for a relatively long disruption of use and the necessity for extensive repairs after an event, then the probability over 50 years of having this problem or worse is in the order of 0.5 to 10% (see figure 5, left).

If one interprets damage grade 3 as being a damage grade for which the building is at the border between reparable with very high costs and complete loss, then the probability of losing the greater part or even the whole value of the building over a period of 50 years is in the order of 0.1% with a variability of ± one order of magnitude.

Are these performances acceptable to an owner for a new building designed according to code? This question has never been thoroughly discussed in Switzerland.

4. IMPROVEMENT POSSIBILITIES

4.1 Finding the economical optimum for human risk and owner's financial risk

It should be analyzed for different building types at what level of seismic action the additional cost for seismic design stops being commensurate to the risk reduction for human occupancy and the owner's financial risk. This approach would target the optimization of the seismic provisions in the domain of direct responsibility (safety of building) and interest (minimization of future losses through investments with a positive cost-benefit ratio) of the building owner.

4.2 Optimize the protection objectives of importance class III buildings

Although not specifically studied, the definition of performance objectives for so-called lifeline structures should be improved in the codes. The importance factor of 1.4 in the current building code SIA 261 is considered by the authors to be too low when considering the risk concentration linked with these critical objects. Furthermore, the performance objectives regarding serviceability should be much more specific and descriptive, as owners, architects and engineers are often confused about how to implement the rather vague code requirements in practice.

4.3 Emphasize conceptual design and constructive measures to reduce property and downtime risks

The level of seismic action and the degree of conservativeness in the design process is only one aspect of the problem. Robustness and damage limitation are greatly influenced by the conceptual design and the implementation of efficient and cost effective standardized constructive measures. To this matter, building codes should put more emphasis on the seismic protection and design of non-structural elements and on the interaction between the structural concept and the protection of non-structural elements.

4.4 Communicate transparently about the protection objectives with building owners

Civil engineers are often unable to explain what is going to happen when the design seismic action occurs and what the seismic design action means in relation to earthquake scenarios. One way to be more transparent towards building owners and allow them to decide if they want more stringent seismic provisions than required by the building codes would be to communicate the expected damage grade when the design seismic action occurs and the probability of exceeding different damage grades over the lifetime of the building. Further information, such as what kind of scenarios are covered by the design seismic action and how much stronger the shaking could be in the epicentral region of a characteristic event (and what the consequences of that would be) would also be helpful. Such communication efforts should be supported by material prepared by national code committees.

4.5 Defining and testing societal protection objectives

In this approach a representative group of all relevant stakeholders (associations of building owners, renters and the private economy, cantonal authorities and insurances) should try to define possible societal protection objectives taking into account the different perspectives of the groups of interests. The possible integration of such societal objectives in the building code provisions could then be evaluated taking into account the achieved risk reduction including societal costs of seismic damage.
This approach would follow the trend of societal resilience. It would require the computation of the risk not only for individual objects, but for the built environment and the welfare of the society as a whole. Central questions like who is obliged or ready to pay for which kind of risk reduction, as well as who is legitimated to enforce which kind of requirements will need to be answered.

5. CONCLUSIONS

This paper shows that a design based on a 475 year return period seismic action for a zone of low to moderate seismicity like Switzerland is adequate regarding the protection of individual lives. Computations show that an annual probability of death in the order of 10^{-6} and lower is generally achieved. However, the seismic provisions may not be optimal regarding the financial risk related to the cost of damage and downtime. This holds true in particular in the case of earthquakes where many structures are hit by the same event, thus increasing the cost and duration of repair. Further studies are needed to determine at what level of seismic action the additional cost for seismic design stops being commensurate to the risk reduction for humans and the financial risk reduction for the owner.

For existing buildings, the minimum compliance factors for structural safety in the building code SIA 269/8 are set so that the annual probability of death remains smaller than 10^{-5}, which is a generally accepted threshold value for natural hazards. Cost benefit analyses show that retrofitting buildings to a higher compliance factor is mostly justified for buildings with a high human occupancy or a very important function linked with high indirect consequences by the loss of functionality. Retrofitting based solely on the risk reduction to property value would be in most cases not commensurate.

It seems logical and desirable that cost-benefit analyses related to the determination of seismic requirements in building codes consider the societal costs of earthquake events. This principle is surely worth investigating but is still far away from being implementable in the buildings codes. Testing possible options would require the involvement of very different stakeholders with conflicting interests would require to answer critical questions such as who is responsible to pay for which risk reduction and who is legitimated to enforce which kind of requirements.

6. REFERENCES

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