Seismic vulnerability inventory of existing building stock and prioritization criteria. Application to High Schools buildings of Pyrénées-Orientales (France)

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SUMMARY:

Public authorities confronted with diagnostic of seismic vulnerability of their existing building stock often wonder how identify buildings for which more complex studies or reinforcement actions have priorty. In Switzerland, the OFEG (Swiss Office for the Environment) applies a method following 3 steps, where the 1st one consists in a seismic inventory of the building stock. The goal of the step 1 is to hierarchize the building stock in 4 classes of priority. This step 1 inventory takes into account the following parameters: 1) the constructive characteristics, which means: age of construction and application or not of seismic codes, structural system, type and disposition of bracing elements, foundation, plan form; 2) the seismic zone from national hazard map within is situated the building and 3) the importance of the building, the number of people indoors, the frequency of occupation during the year and the economic value of the building. All these parameters are evaluated using a check-list and they are combined into two numerical indicators: WZ damage probability and AZPS potential losses. Four combinations of these two indicators are used to obtain the 4 priority groups. This article presents the adaptation done to French continental context of OFEV's method step 1 and the comparison with results using standard visual vulnerability diagnostic forms which do not considers explicitly occupancy or building value. The method has been applied for whole buildings of public Secondary Schools managed by the Languedoc-Roussillon Regional Council in Pyrénées-Orientales French department.

Keywords: vulnerability, prioritization criteria, Pyrenees

1. INTRODUCTION AND OBJECTIFS

This work presents the application in a pilot site in France of the OFEVs (Swiss Federal Office for the Environment) method to inventory buildings considering seismic vulnerability (OFEG 2005). The method follows 3 steps where the first one is a simplified approach which allows a first selection of the buildings with a higher priority to be engaged to next step.

Only the first step has been applied on the whole building stock of public High School of the Pyrenees-Orientales French department. The owner is the Languedoc-Roussillon Regional Council.

The applied method has an innovative character because it takes into account not only physical vulnerability aspects but also population occupation of buildings and economic value. Secondly, the application into a different national context, in this case Metropolitan France, shows the good way to identify the problems to adapt the method into another country.

Finally the objective was to provide the owner of the buildings, in this case the Languedoc-Roussillon Regional Council, a tool to integrate the seismic risk in the management of their building stock.

2. OFEV METHOD OF STEP 1

The Federal Office for the Environment (OFEV) in Switzerland is responsible for identifying government buildings in Eurocode 8 classes II and III and to locate it in seismic hazard zones 2 and 3 (according to SIA 160, Swiss seismic code). The OFEV decided to develop and implement a three-stage approach. The first step is to identify briefly the main structural characteristics of buildings and the seismic risk they are exposed, using the architectural plans and if necessary a field visit. In a second step, it is necessary to further examine the risk in certain buildings, based on engineering plans. The third phase is to develop remediation of a reduced number of buildings at particular risk, and realize where appropriate (OFEG 2005).

In step 1, the important characteristics of the building are identified with architectural plans and a possible visit. The seismic risk is then evaluated on the basis of a checklist (approx. 4 hours per building). The risk assessment from step 1 does not require a detailed calculation and does not deliver results in absolute terms. Its aim is rather to identify the prior buildings using structural and soil indicators that determine their seismic resistance and to assess the risk to exposed buildings, people and property.

The risk index RZPS is defined as the product between the WZ factor (collapse probability, factor taking into account seismic hazard and vulnerability parameters) and the AZPS factor (potential losses, people and economic value):

$$RZPS = WZ * AZPS$$

The four groups of priority are defined in function of WZ and RZPS values. As a first assumption this classification is proposed by the OFEV:

- Priority 1 group : WZ>65 and RZPS>500
- Priority 2 group : WZ<65 and RZPS>500
- Priority 3 group : WZ>65 and RZPS<500
- Priority 4 group : WZ<65 and RZPS<500

The priority ranking is from the clues RZPS and WZ (Figure 3).

AZPS factor is defined as a function of the importance of building (AIF), the potential material losses (ADS) and the potential human losses (ASP):

$$AZPS = AIP*(ADS+ADP).$$

The method is explained in the following references, OFEG (2005) and Kolz et al. (2010).

The factor AIF represents the importance of the building coming from Swiss seismic code. French seismic code presents a little difference, consequently buildings of importance class I & II on French code are grouped:

Table 2.1. AIF factor, building importance.

AIF	Swiss code	Importance factor in French code
1	I	I and II
2	II	III
5	III	IV

The factor ADS evaluates the potential material losses. Originally this factor takes into account the insurance value of each building. The application into Pyrénées-orientales High schools takes into account the gross floor area in m² and this value has been transformed in euros within a ratio 1500€/m².

ADP coefficient looks at the potential human losses. It takes into account occupancy of the building during a year. For this work, interviews with the Administration of each High School allow knowing the total number of students, the occupancy during the week and a year. After that, ratios as "students per classroom" and "classrooms per building", permits to estimate the total number of students per building during journeys. Some particular cases have been identified, as for example the mixt buildings with classrooms and dormitories, which have 100% of occupancy all day during academic year but with different ratios during the journey or during the night.

WZ factor represents the collapse probability

The calculation of this factor WZ in Switzerland is based on the following assumptions (OFEG 2005):

- The probability of building collapse is ten times lower if the building is located within Zone 1 (lowest seismic hazard zone in Switzerland) than if it is within the zone 3b (highest seismic zone).
- Taking a building constructed over a medium quality soil as a reference, the probability of collapse is halved if it is based on good soil and it is doubled over rough terrain.
- The probability of building collapse is the same in all areas of seismic hazard if it has been designed in accordance with the Swiss seismic code SIA 160 of 1989 (updated in SIA 261 in 2003).
- The probability of collapse of a building located within seismic zone 1 is three times greater if it was designed before 1970 unless it was designed and built after 1989 according to seismic code SIA 160. In the seismic zone 3b, the ratio is fifteen to one.
- The probability of collapse of a building designed appropriately in all respects, and especially face to the earthquake, is about 20 times lower than if poorly designed at any point of view.

For the application in France in the present work these assumptions has not been modified heavily. The only modification was to consider the French seismic code PS92 (dating from 1992) the equivalent to Swiss code SIA160 dating from 1989. The separation between buildings prior to 1970 has been conserved because the first generation of seismic codes in France started in the early 1970s (PS69).

The WZ factor is calculated as follows:

$$WZ = WEP \times WB \times (1 + WG + WA + WW + WK + WD + WF)$$

being WEP a factor about the seismic hazard and the application of seismic codes, WB factor about soil conditions and WG, WA, WW, WK, WD and WF vulnerability factors.

The WEP factor considers the seismic zone and the year of the project. In Switzerland there are 4 seismic hazard zones: 1, 2, 3a and 3b. Some difficulties appear to adapt this parameter to French continental context. These criteria should be read as a probability of seismic hazard or as the acceleration which has been considered into calculations of seismic design? In the French case, where the seismic map has changed (the newest one dates from October 2010) some difficulties appeared.

As a first hypothesis, the newest French seismic map has been considered (Table 2.1). The comparison between French and Swiss zones has been done looking at the acceleration values. The Swiss seismic zone 3a does not have an equivalent zone on French map. The seismic zones 1 and 2 in France are grouped as an equivalent of Swiss zone 1. More detailed works should be done, especially to better understand the effect on municipalities which has been outclassed with the new seismic map in France.

Table 2.2. WEP factor. Comparison between the Swiss seismic zones and the French ones.

French seismic hazard zone	1 and 2	3	4	Swiss seismic hazard zone	1	2	3a	3b
Year \acc.	0.4 and 0.7 m/s^2	1.1 m/s^2	1.6 m/s^2	Year\acc.	0.6 m/s^2	1.0 m/s^2	1.3 m/s^2	1.6 m/s^2
<1970	3	6	30	<1970	3	6	15	30
1970-1992	2	3	15	1970-1989	2	3	8	15
>1992 (PS92)	1	1	1	>1989	1	1	1	1

WB is the parameter soil, which is evaluated as follows:

- WB = 1 for rock or a very compact soil (soil classes A and B according to SIA 261 (2003));

- WB = 2 is to choose for soil class C, D and E according to SIA 261 for which no effects (liquefaction, thixotropic, landslides) or significant amplification due to the geometry of the bedrock is expected.

- WB = 4 is to be chosen for the soils where induced effects such as liquefaction, thixotropic or landslides are expected (soil class F according to SIA 261), and for cases where a strong amplification due to the geometry of bedrock is expected (possible for soil classes C, D and E).

This parameter, WB, was evaluated for each High School using the geological maps from BRGM at 1:50000 and the French borehole database (BSS) which contains geological and geotechnical information. The type of soil was considered homogeneous for the each High School.

The intrinsic vulnerability factors are the following ones. There are not regional factors so they have been applied directly to French case:

WA. Vertical bracing. This factor looks if there is continuity between the bracing. The most penalized case is the soft story (Table 2.3).

Table 2.3. WA factor, vertical bracing.

Vertical bracing	WA
Vertical continuity	0
Discontinuity	2
Soft storey or transparency	5

Figure 2.1 : parameter WA, examples of vertical bracing. a) bracing elements (shear walls) continuous on vertical, b) discontinuity between the 1st floor and the 2nd and c) soft story.

WG: bracing on plan. It looks if the bracing elements are disposed symmetrically or not in plan (Table 2.4).

Table 2.4. WG factor, bracing on plan.

Bracing on plan	WG
Adequate, bracing on the 2 directions	0
Wrong, bracing on only 1 direction, high asymmetry	2
No bracing	5

WK: form. It penalizes irregular forms in plan (Table 2.5).

Table 2.5. WK factor, form.Form	WK
Regular	0
Irregular	1

WW: bracing type. Bracing walls, RC frames and infill walls, mixt, steel frames. The most penalized case is RC frames and infill walls, the lowest the walls (Table 2.6).

Table 2.6. WW factor, bracing type.

Nature of the bracing	WW
Walls	0
RC frames without infill walls	1
Frames and X brace	2
RC frames and infill walls	2 to 4
Dual system	3

Some difficulties appear to apply these parameters to unreinforced stone masonry buildings existing in some High Schools. For this kind of buildings the highest factor (4) has been considered.

WD: ductility. It takes into account the material of construction. The most penalized case is unreinforced masonry buildings with flexible slabs.

Table 2.7. WD factor, ductility.

Ductility	WD
RC, steel, composite	0
Reinforced masonry	2
Wood, prefabricated	3
Unreinforced masonry, unreinforced concrete - flexible slabs (wood, prefabricated) - rigid slabs (RC)	 3+number of floors 3+number of floors/2

WF: foundation type.

Table 2.5. WF factor, foundation.

Foundation	WF
All the surface	0
Isolated, over an heterogeneous terrain	1

Figure 2.2.: parameter WA, examples of different structural systems. A) Traditional stone and brick U masonry, B) RC frames and infill walls, C) wood structure, D) steel structure and infill walls, E) masonry and RC structure and F) prefabricated building.

3. RESULTS

Calculation of WZ & AZPS for each building allows a hierarchization of the building stock (127 buildings disseminated on 14 High Scholls) following 4 classes as described above (figure 3.1).

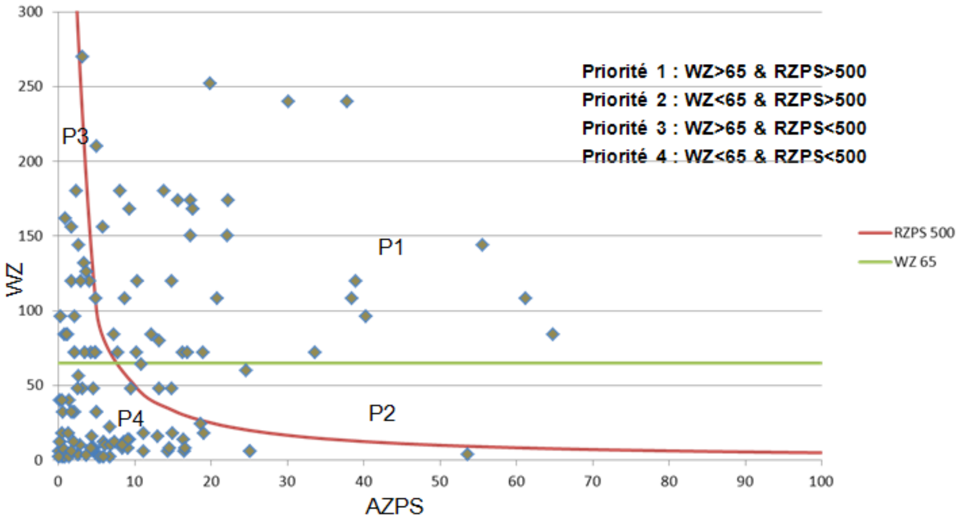

Figure 2.1. Classification into the 4 groups of priority for the whole building stock.

The buildings which are classed into Priority 1 group are generally those with no seismic conception and a big importance factor, in terms of people occupancy and economic value. In general they correspond to buildings with not enough bracing elements on one direction.

Few buildings are classed into Priority 2 group; they have moderate vulnerability (not enough vulnerable to be classed into Priority 1) but great importance in terms of occupancy and economic value. Some buildings conceived with the first generation of seismic code in France (built during the 1970s and 1980s) are classed in priority 2.

Buildings classed into the priority group 3 are those with relevant vulnerability but with a low importance (for example, buildings which are not used as classroom, little buildings with low surfaces).

Finally, into priority 4 are founded buildings conceived with the newest seismic code or with the precedent one (PS69) without great defaults.

There was only a High School situated within the highest seismic level in France continental. Consequently the buildings of this centre tend to appear with higher levels of priority.

A 29% of buildings have been classed in priority 1. Even there are a considerable number of centres built prior to seismic codes, only the most important buildings in terms of occupancy and economic value appears into this group. A large number of buildings (51%) are classed in priority 4, as a consequence of the great number of High Schools of Pyrenees Orientales department which has been constructed completely or partially during the last 20 years.

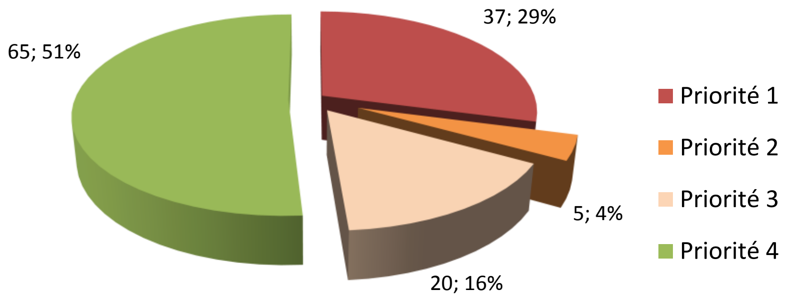

Figure 3.2.distribution of the analysed building stock into 4 priority groups.

4. CONCLUSIONS AND PERSPECTIVES

Generally it is observed a strong correlation between the age of construction of buildings and the priority ranking obtained by the OFEV method of step 1. This is due to the factors of the method, which penalises heavily buildings without seismic conception, but also to changes in construction practices clearly visible during the field trip. The structural system of scholar building stock has gradually evolved from RC frames and infill walls (before 1975) to RC shear walls (after the 1980s). And in general, recent buildings have less default on the structure as soft storeys, balconies, vertical irregularities, etc. As a consequence, the criteria “age”, has not only a direct implication on application of seismic code but implicitly also on structural type.

Evaluation of the parameter AZPS (indicator for potential losses and economic value) appears a good way to quantify the importance of a building with the goal to hierarchize it between buildings with more or less the same physical vulnerability.

Some particular cases are the recent buildings which present important vulnerability factors. Seismic design is presumed for all recent buildings, consequently the factor WZ will rarely be higher than 65 and they will be classed in priority 4 almost always. Nevertheless this vulnerability points in the structure should be verified if they are really acceptable or not.

The adaptation to the French context presents some difficulties. In terms of regulatory soil acceleration and seismic map, there are two possibilities: 1) the acceleration which has been considered into the calculations of the buildings which means consider, for old buildings, acceleration values from old seismic maps; 2) the acceleration which is considered in nowadays French seismic code.

This method seems to be well adapted to RC structures. However, there is not a clear distinction between different types of unreinforced masonry which can be found in France (bricks, stone or breeze block) even for public buildings. As Podesta (2012) has proposed it should be proposed to separate clearly the assessment for RC buildings and for masonry buildings because the parameters should not be the same ones.

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