# The Swiss procedure for the evaluation of seismic vulnerability of existing buildings

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**SUMMARY:**
The Swiss authorities have recently put into place a codified procedure for the seismic risk evaluation of public structures. This methodology has been developed by the *Office Fédéral des Eaux et de la Géologie* (OFEG) and is based on a three-step general procedure for the evaluation of the seismic risk.
The first step is a simplified method and has been developed without any calibration through comparison with actual damage observed after seismic events. This leads to a high level of uncertainty regarding the reliability of the method.
This body of work aims to rectify this by evaluating the reliability of the Swiss procedure by applying the method to Italian structures damaged by the 2002 Molise earthquake.
The method has been examined in its aim to provide priority lists for a limited number of structures and in defining damage scenarios on a territorial scale. The analyses carried out used masonry structures.

*Keywords: seismic vulnerability analysis, simplified procedure , Switzerland*

## 1. INTRODUCTION

Seismic risk analysis at a territorial level is important for both the development of prevention strategies and post-earthquake emergency management. Indeed these analyses, on the basis of exposure and vulnerability data of the built environment, allow to obtain an assessment of damage scenarios on a territorial level representative of a possible estimation of damage on the investigated area, as a result of a well-defined seismic event.
In specific reference to vulnerability assessment of the built environment, in order to be applicable on a territorial scale, models have to necessarily be based on a few easily available data by reason of the sample size to be treated. Being simplified models, their validation is searched through comparison with the actual damage observed after seismic events.
Many models for the evaluation of the seismic vulnerability of existing buildings have been suggested for the Italian peninsular (Bernardini et al. 2009, Cattari et al. 2010, Cattari et al. 2009, Giovinazzi et al. 2007), however none of these procedures has been adopted in the Italian codes, with the exception of the method proposed by 9th February 2011 Ministerial Decree for cultural heritage buildings (DPCM 9/2/2011). In contrast and despite a low level of seismic hazard, the Swiss authorities have recently put into place a codified procedure for the seismic risk evaluation of public structures. This methodology is based on a three-step general procedure for the evaluation of the seismic risk. In particular the aim of the first step is to provide a list where buildings are ranked according to their seismic risk, thus enabling buildings requiring more detailed analyses (steps 2 and 3) to be identified.
The model is necessarily simplified and an application to the Italian structures damaged by recent seismic events allow us to specify some remarks regarding the reliability of the method also in reference to the Italian built environment. Indeed in this body of work, after analysing the methodology proposed in the document "*Vérification de la sécurité parasismique des bâtiments existants, Concept et directives pour l'Etape 1*" (OFEF 2005), denominated Fiche I, it has been applied to Molise structures damaged by the 2002 earthquake.

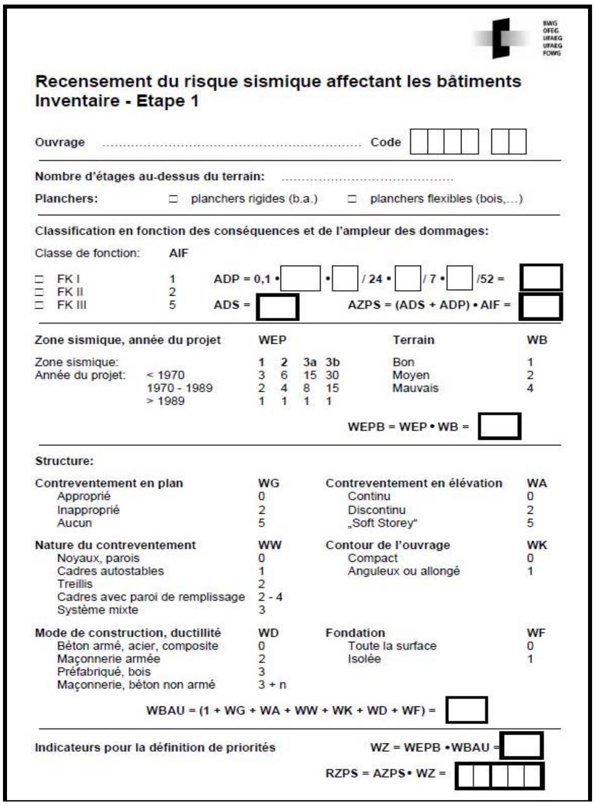
On the basis of the shortcomings identified during the first phase of Fiche I application, a proposal for changes of the form has been defined. These changes have been suggested with the intent of making Fiche I applicable with more reliability to masonry structures, keeping the expeditious nature of the form. The modified form has been reapplied to the case study of Ripabottoni, previously analysed, in order to compare the obtained risk evaluation to the actual damage observed.

## 2. THE SWISS PROCEDURE FOR SEISMIC RISK ASSESMENT – STEP 1

According to the decision of the Federal Council on December 11th, 2011, all the transformation and renewal designs of Switzerland, as well as all existing Swiss buildings with a function class equal to II and III should be verified concerning seismic safety and, if necessary, reinforced taking into account the proportionality of the costs.
For existing Swiss structures for which the amount of antiseismic protection costs is between 2% and 10% of the structure value, it is necessary to define priority lists of intervention and to distribute interventions over several decades.
To do this, the OFEG (*Office Fédéral des Eaux et de la Géologie)* decided to develop and adopt a three-step general procedure for the evaluation of the seismic risk in order to guarantee a rational use of means.

### 2.1. Fiche I

The first step of the procedure involves the identification of the important characteristics of the building using architectural drawings and eventually performing onsite inspection. The seismic risk is evaluated in a simplified way using a checklist and the risk evaluation is not then based on detailed calculations, but provided through a relative building score.
The checklist presented in the form in Fig 2.1. is useful to define the risk factor RZPS as a product of the personal and material damage factor AZPS and the collapse probability factor WZ.


BWG OFEG UFAEG UFAEG FOWG

**Recensement du risque sismique affectant les bâtiments**
**Inventaire - Etape 1**

Ouvrage .............................................. Code

Nombre d'étages au-dessus du terrain: ..............................
Planchers: ☐ planchers rigides (b.a.) ☐ planchers flexibles (bois,…)

Classification en fonction des conséquences et de l'ampleur des dommages:
Classe de fonction: AIF
☐ FK I 1
☐ FK II 2
☐ FK III 5
ADP = 0,1 • ☐ • ☐ / 24 • ☐ / 7 • ☐ /52 = ☐
ADS = ☐
AZPS = (ADS + ADP) • AIF = ☐

| Zone sismique, année du projet | | WEP | | | | Terrain | WB |
|---|---|---|---|---|---|---|---|
| Zone sismique: | | 1 | 2 | 3a | 3b | Bon | 1 |
| Année du projet: | < 1970 | 3 | 6 | 15 | 30 | Moyen | 2 |
| | 1970 - 1989 | 2 | 4 | 8 | 15 | Mauvais | 4 |
| | > 1989 | 1 | 1 | 1 | 1 | | |

WEPB = WEP • WB = ☐

Structure:

| Contreventement en plan | WG | Contreventement en élévation | WA |
|---|---|---|---|
| Approprié | 0 | Continu | 0 |
| Inapproprié | 2 | Discontinu | 2 |
| Aucun | 5 | „Soft Storey" | 5 |
| **Nature du contreventement** | **WW** | **Contour de l'ouvrage** | **WK** |
| Noyaux, parois | 0 | Compact | 0 |
| Cadres autostables | 1 | Anguleux ou allongé | 1 |
| Treillis | 2 | | |
| Cadres avec paroi de remplissage | 2 - 4 | | |
| Système mixte | 3 | | |
| **Mode de construction, ductillité** | **WD** | **Fondation** | **WF** |
| Béton armé, acier, composite | 0 | Toute la surface | 0 |
| Maçonnerie armée | 2 | Isolée | 1 |
| Préfabriqué, bois | 3 | | |
| Maçonnerie, béton non armé | 3 + n | | |

WBAU = (1 + WG + WA + WW + WK + WD + WF) = ☐

Indicateurs pour la définition de priorités
WZ = WEPB •WBAU = ☐
RZPS = AZPS• WZ = ☐

**Figure 2.1.** Fiche I

The AZPS factor, which defines losses that will appear after an earthquake due to the structure collapse or the losses of its function, depends on two parameters: the direct material and personal damage factor AD (ADS+ADP) and the indirect damage factor AIF. The direct material damage factor ADS represents the amount of damage to a building at the time of its more or less complete collapse and roughly corresponds to its insurance value, increased by the cost to clear rubble and its value content. The direct personal damage factor ADP depends on the mean occupancy of the building and is defined according to: the average number of people present in the building every day N, hours per day H, days per week G and weeks per year S when the building is occupied. The indirect damage factor AIF measures the consecutive or secondary damages, which are that caused by the difficulty to intervene or interruption of emergency services and by the dispersion of dangerous substances from industrial equipment or stores. It is provided in a simplified way according to the function class of the structure.

The WZ factor expresses the probability that a building will have a more or less complete collapse as a consequence of a well-defined seismic event. This is not an absolute value, but one that allows comparison between the structures. The collapse probability is expressed as a product of the WEPB and WBAU factors, where, in turn, WEPB depends on two parameters: WEP and WB. The WEP factor depends on the seismic zone and the project year while WB on the foundation soil. Instead the WBAU parameter is calculated as a sum of 6 factors that relate to structural characteristics: WG concerns the arrangement of the bracing elements in plane; WA the arrangement of the bracing elements in elevation; WW the type of bracing system; WK the building in plane shape; WD the ductility and WF the foundation type.

Regarding the factor which refers to the seismic zone and the project year (WEP), it is stressed that the first Swiss code with seismic prescriptions is represented by the code SIA 160 which came in effect in 1970, followed by the code SIA 160 in 1989, which corresponds to current technical knowledge. The WB indicator considers the so-called “site effect”, on the basis of soil characteristics of the investigated area. Every factor value corresponds to given soil classes, indicated in the code SIA 261 (2003). The bracing elements, which have to absorb horizontal forces, play a particularly important role in the seismic behaviour of the load-bearing structure. In order to evaluate the WG factor, a favourable arrangement of the bracing elements in plane is defined when the stiffness centre coincides with the mass centre. As the bracing elements and the building in elevation shape affect the respective oscillatory behaviour at the time of an earthquake, the WA factor varies according to whether the bracing elements are continuous or not continuous. After the latest earthquakes, it has been observed, in fact, that, if possible, the stiffness has to be identical for all storeys. It’s a good rule to avoid stiffness change, particularly, suppression of the bracing elements and other discontinuities in the force path. In addition another vulnerable configuration is the presence of soft storey, a storey without or with poor horizontal stiffness. The quality of the bracing system depends on its type. According to the form, in the definition of the WW factor, cores and walls in r.c. are the most suitable system, followed by moment-resisting frames, a less rigid system; braced frames are characterised by a high stiffness and so it is a less suitable system in order to support the forces generated by earthquake; the worst strength affects infilled frames. Another factor considered in the checklist, which contributes to evaluating building strength to earthquake is WK, which refers to the building’s in plane shape. Long shapes with angles are an unfavourable configuration. The structure’s behavior under the action of an earthquake depends on both its strength and ductility or deformability. Since the exhaustive assessment of ductility demands detailed knowledge of the structure, which is outside of what is required in this first phase of evaluation, the form takes into account this perfunctorily, in the WD factor, on the basis of the construction method and the materials used for the load-bearing elements of the structure. Finally, it is stressed that an earthquake is able to generate differential displacements in the subsoil and among the foundations, which may cause excessive stresses locally and so lead to the building’s collapse. Structures equipped with isolated foundations or ground beam foundations without cross connections are particularly at risk. The form takes this into account through the WF factor.

### 2.2. Definition of priority lists

As can be seen in Fig.2.2., in which some points associated with WZ and certain AZPS values are

represented, the selection of buildings which are earthquake prone buildings is defined by choosing threshold values for the WZ and RZPS factors. On the occasion of the federal Swiss inventory, concluded in 2004, the discriminating values 65 and 500 were fixed for WZ and RZPS, for instance, in order to define the intervention priorities.
Threshold values are not fixed, but vary depending on the type of the buildings analysed, so they depend on the distribution of the WZ (or RZPS) factors. In other words, on the basis of the distribution of the factor values, the value which allows one to isolate the desired percentage or number of buildings is chosen each time.

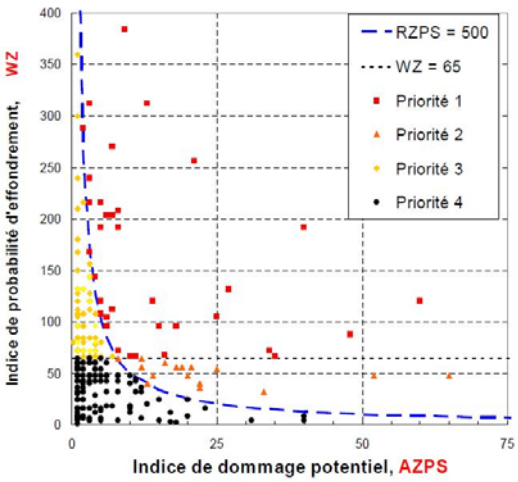



**Figure 2.2.** Priority definition according to the federal Swiss inventory 2001 – 2004

## 3. RELIABILITY EVALUATION OF FICHE I THROUGH APPLICATION TO THE ITALIAN TERRITORY

In order to test the reliability of the methodology based on Fiche I, its application is presented to the old town centre of Ripabottoni, mainly characterized by masonry structures, of which we have a detailed report including the damage observed after the 2002 earthquake.
It is stressed that Swiss masonry buildings, especially if referring to historical buildings, are characterized by structural elements, construction techniques and antiseismic devices which may be considered similar to those of Italian masonry structures. Perhaps the Swiss historical built environment is less then that present in Italy, however it is pointed out that Fiche I is especially planned for r.c. structures, denoting the demand to introduce new criteria.

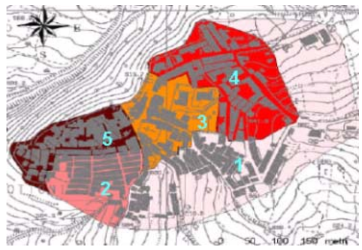
### 3.1. Buildings characteristics of Ripabottoni affected by the 2002 earthquake

The two earth tremors on 31$^{st}$ October, 2002 (Ml = 5.4) and 1$^{st}$ November, 2002 (Ml = 5.0) and the next earthquake swarm composed of more than 1000 aftershocks, affected some municipalities on the border between the Molise and Puglia regions. As a consequence of these earthquakes, the National Group for Earthquake Defence (GNDT) of the National Institute of Geophysics and Volcanology (INGV) carried out some research on the built-up area of Ripabottoni (Lagomarsino et al. 2003, Lemme et al. 2008). In particular a survey of construction characteristics and seismic vulnerability of all masonry buildings was completed, through a methodology base on an expeditious form.
Most of the built-up area buildings, represented in Fig.3.1, are designed for residence, built before 1919 and distributed mainly on three levels. Vertical elements in most cases are uncut stone masonry walls with a horizontal bond and sack walls; wall leaves, of which there are two, are merely placed together or badly connected. Horizontal elements in most cases are timber, steel beams and tiles floors with wooden roofs.
The built-up area of Ripabottoni has been divided, through a study of microzonation, into 5 zones with homogeneous seismic behaviour (Tab.3.1.).

**Figure 3.1.** Plan of Ripabottoni old town centre

**Table. 3.1.** Zones characteristics with an homogeneous seismic behaviour

| ZONE | POSITION | GEOLOGY | STEEPNESS |
|---|---|---|---|
| 1 | South-East | S. Bartolomeo Flysch, Argille varicolori | Medium |
| 2 | South-West | S. Bartolomeo Flysch | Medium-high |
| 3 | Central | S. Bartolomeo Flysch Argille varicolori | Medium-low |
| 4 | North-East | S. Bartolomeo Flysch | High |
| 5 | North-West | S. Bartolomeo Flysch | High |



*3.1.1. Damage observed in the old town centre of Ripabottoni*

The 2002 earth tremors caused localized buildings damage in particular zones of the built-up area. Damage observed information was both acquired from the databases relating to safety-usability surveys made during the seismic crisis, through AeDES forms (Bernardini 2000), and directly observed through investigations.

Damage and safety-usability data, relating to 608 buildings analysed, are summarized in the graphs shown in Fig.3.2. The correlation between damage and safety-usability data is represented in Fig.3.3a., we notice that with the increasing of not safety-usability level we have a greater damage distribution. This demonstrates a certain trustworthiness between damage and safety-usability.

It is stressed that the building height does not seem to influence the safety-usability result significantly. On the contrary the geographical position is very influential in the safety-usability distribution, shown in Fig.3.3b.: in particular the presence of greater damage in zone 5 is remarked.

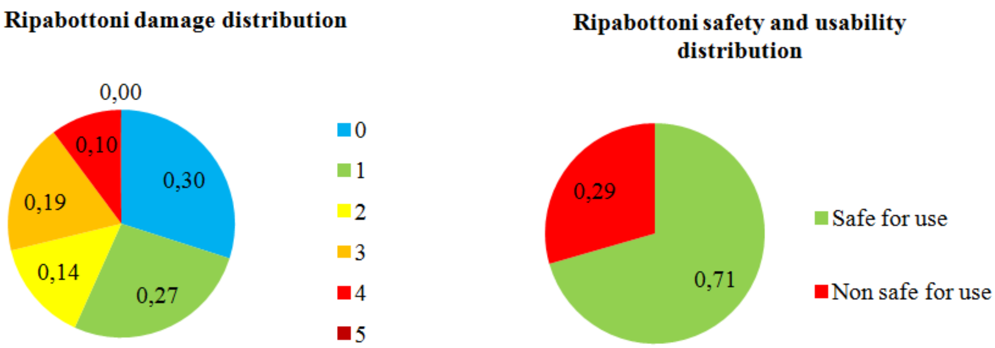



**Figure 3.2.** Percentage of damage and safety-usability level of Ripabottoni masonry buildings

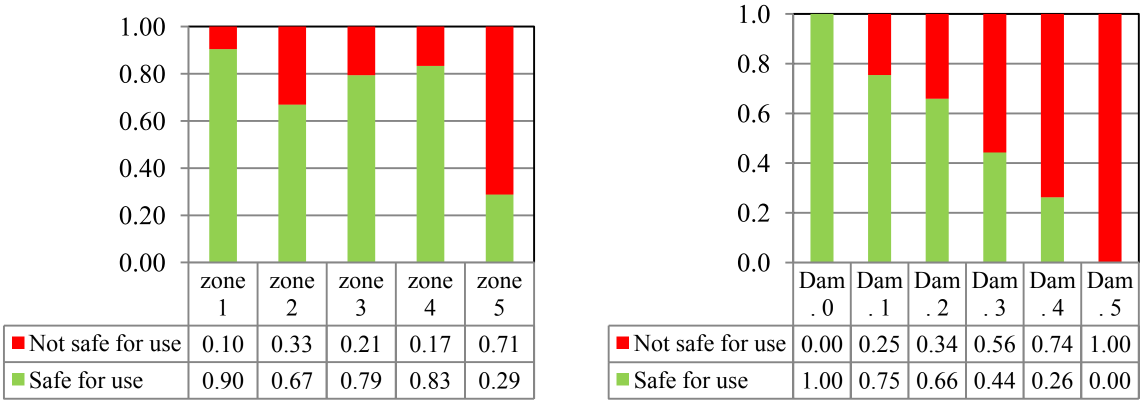



**Figure 3.3.a)** Correlation between damage states and safety-usability result
b) Safety-usability distribution on the base of Ripabottoni zones

### 3.2. Application to Ripabottoni masonry buildings: comparison between expected and observed damage

The results obtained through the first Fiche I application to Ripabottoni built environment in terms of correlation between the collapse probability factor WZ and the safety-usability result are reported.
It was decided to divide the obtained values into 3 ranges (WZ≤450; 450<WZ≤550; WZ>550) using a physical type rule, as the method aim is to define priority lists in the perspective of a territorial planning. The first range has the task of selecting the largest part of the buildings which are not very vulnerable, the second one defining a situation of uncertainty and the third one isolating a part of very vulnerable buildings, which probably need interventions. The thresholds, in this first application, are defined in order to equitably distribute the WZ values in the ranges. The histogram trend in Fig.3.4. shows how the Fiche I model, for masonry buildings, is unable to define, in probabilistic terms, reliable damage scenarios as a result of a seismic event of given intensity; in fact the percentage of safe for use buildings after the earthquake does not decrease with the increasing of the WZ value.

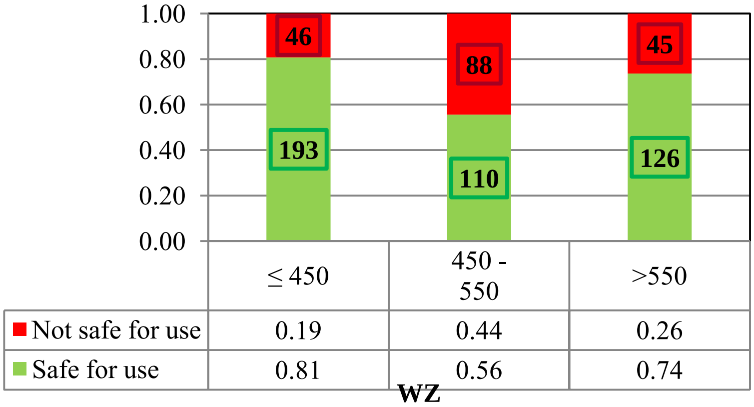



**Figure 3.4.** Correlation between WZ and safety-usability result using the original form

## 4. IMPROVEMENT SUGGESTIONS FOR FICHE I

On the basis of the results concerning Fiche I application to the Molise built environment, it's possible to make some comments and to suggest changes to the form designed to obtain results more in accordance with the observed damage after seismic events. These changes have been suggested in order to make Fiche I applicable with more reliability to masonry buildings, always with the intent of keeping the expeditious nature of the form. The modified form has been reapplied to Ripabottoni comparing the obtained risk estimation to the actual damage observed in order to establish the improvement.

## 4.1. Changes and new parameters insertion

On the basis of the shortcomings identified during the first phase of Fiche I application, a proposal for changes to the form has been defined. In the matter of the WB factor, referring to the foundation soil type, it is proposed to make direct reference to the soil classification defined in the document SIA 261 (2003). The Swiss territory, in fact, is covered with seismic microzonation maps which define local hazard for every location. The author suggests, in the following table (Tab.4.1.), a new definition for the WB parameter. Ripabottoni is characterized by a soil classified as B.

**Table 4.1.** The WB factor

| **Foundation soil classification** | Spectra parameters according to SIA 261/2003 | | | | **WB** |
|---|---|---|---|---|---|
| | S [-] | $T_B$ [sec] | $T_C$ [sec] | $T_D$ [sec] | |
| A | 1 | 0.15 | 0.4 | 2 | 1.0 |
| B | 1.2 | 0.15 | 0.5 | 2 | 2.5 |
| C | 1.15 | 0.20 | 0.6 | 2 | 2.1 |
| D | 1.35 | 0.20 | 0.8 | 2 | 3.6 |
| E | 1.4 | 0.15 | 0.5 | 2 | 4.0 |
| F | - | - | - | - | - |

Another important parameter, which is not taken into account in the definition of the collapse probability WZ, is the structure's topographic location. This parameter is important for the particular conformation of the Swiss territory, characterized by mountains and hills with steep slopes.
The 4 values of topographic category are those defined in EC8 (prEN 1998-1 2003), the author suggests to multiply WT by the WB factor directly in the calculation of the collapse probability factor WZ.
Information which allows to recognize the arrangement of the bracing elements in plane is not present in the survey form used for the Ripabottoni study case. For this reason, considering that the bracing elements of a masonry building are its bearing walls, it was decided to differentiate the behaviour way on the basis of the structure regularity, which is surveyed by the expeditious form. In the table (Tab.4.2.) the criterion used in order to define WG for the specific case of Ripabottoni is shown.
For the same structure regularity conditions, the presence of well connected floors produces better behaviour than that referring to a poorly connected condition.

**Table 4.2.** The WG factor

| | Expeditious form information | | **WG** | |
|---|---|---|---|---|
| Bracing elements in plane | Regularity | Horizontal elements | Rigid floors | Flexible floors |
| Favourable in both directions | Regular | Well connected | 0 | 1 |
| Favourable in only one direction | Regular | poorly connected | 1 | 2 |
| Unfavourable | Regular | poorly connected | 2 | 3 |
| None | Regular | poorly connected | 5 | 5 |

The author suggests a further differentiation in the WD factor definition, for masonry buildings, based on the identification of the masonry type in terms of good or poor quality of the masonry.
As can be seen in the table (Tab.4.3.), the choice to take a dependency linked to "n/2"instead of "n", derives from the considerations of the data observation of Ripabottoni where the percentages of safe and not safe for use buildings remain constant with the changes of the number of building floors.

**Table 4.3.** The WD factor

| Masonry | WD |
|---|---|
| Good quality | 2.5+ n/2 |
| Poor quality | 5+ n/2 |

It is remarked that Fiche I does not take into account the possibility of having linear foundations, characterized by ground traverse beams. This constructive type is better, from a seismic point of view too, than isolated foundations, but it is more vulnerable than shallow foundations with only mat. Therefore, it is suggested a intermediate value equal to 0.5 for WF which is related to this type. The author suggests a factor insertion linked to maintenance condition and/or structural instabilities on the basis of available data for the old town centre of Ripabottoni. Lack of maintenance and the presence of a widespread or serious cracking state places the structure in a condition of greater vulnerability, despite the quality of the structural system. So it is suggested the WS factor, which is able to decrease and increase the vulnerability system (WZ) depending on the preservation state of the building (Tab.4.4.).

**Table 4.4.** The WS factor

| Preservation state | WS |
|---|---|
| Good preservation state | 0.8 |
| Medium preservation state or superficial cracks | 0.9 |
| Poor preservation state  or medium cracks | 1 |
| Very poor preservation state or serious cracks | 1.2 |

### 4.2. Application of the modified Fiche I to Ripabottoni masonry buildings

On the basis of Fiche I changes, after analysing the results using one change at a time, in order to note the real improvement arising, the author considers the application with all the changes at the same time. In this phase the author did not want to make a deduction about the definition of an absolute safety or unsafety threshold, so it is decided to represent the comparison between WZ and safety-usability using the same ranges of the first application, as shown in Fig.4.1.

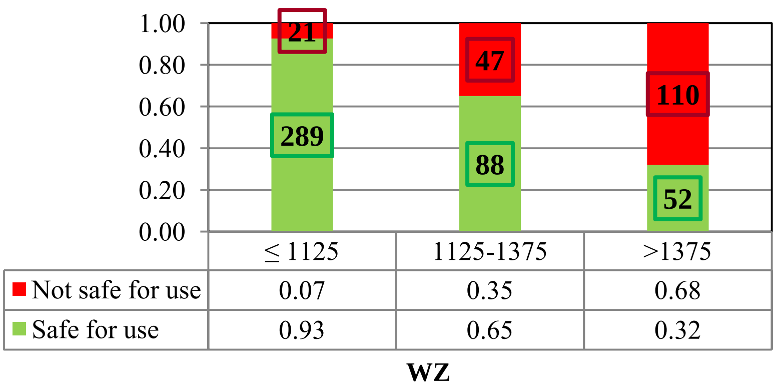



**Figure 4.1.** Correlation between WZ and safety-usability using the modified form

For the final comparison with the first application, the ranges have been multiplied by 2.5, equal to the WB modified value, because the WB factor multiplies the collapse probability factor WZ directly. It’s possible to see a noticeable improvement in results.

In particular, we notice that in the first range of the graph there are a few more than 300 buildings with a percentage of safety-usability of 93% and in the range WZ >1375 there are 162 buildings characterised by a not safety-usability percentage of 68%.

*4.2.1. Thresholds definition*

Another aim was to understand if it was possible to define some safety or not safety thresholds for buildings contextualizing the problem to the site hazard and building type.

It is possible to define the WZ limits which identify the predominant percentage of safe for use and not safe for use buildings. In Fig.4.2a. a preliminary evaluation of WZ threshold for the study case of Ripabottoni is represented. In this first suggestion the author look for WZ values which allow to isolate a sample percentage of 80% in the single range, of buildings respectively safe and not safe for use.

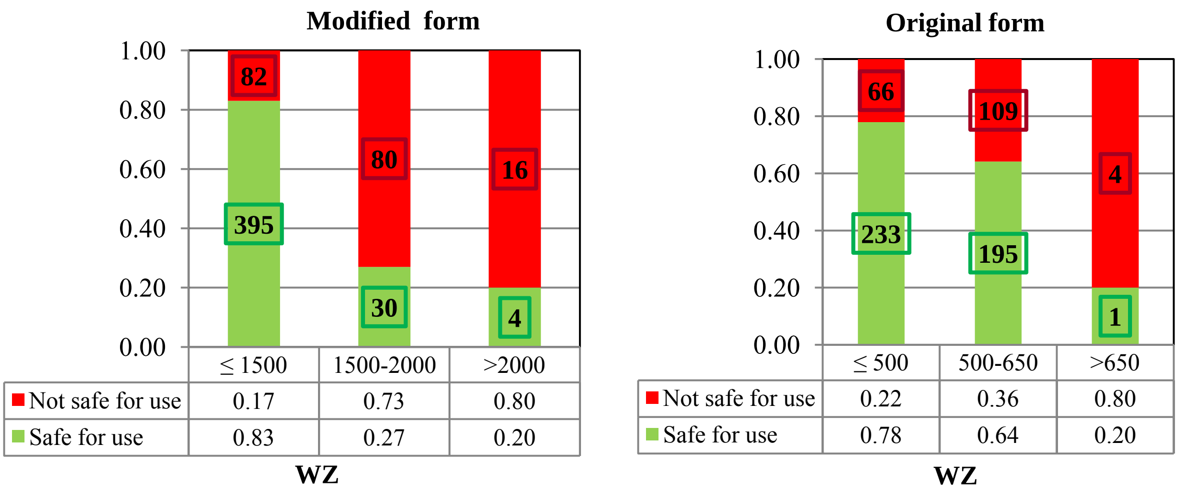



**Figure 4.2.** a,b) Correlation between WZ and safety-usability using the modified and original form with ranges chosen to represent WZ thresholds

It is remarked, in any case, that WZ values obtained can be considered significant only for a built environment with similar characteristics to those of Ripabottoni historic centre and a similar risk level.

The same kind of approach has been applied to the results of the original Fiche I application shown in Fig. 4.2b. The accepted percentage of error is the same as the previous distribution, causing a new definition of the threshold values and a significant difference in terms of number of buildings in every range. It is possible to make some comments, comparing Fig. 4.2a. and 4.2b.:

• Analysing the histograms referring to safe for use buildings, the author notices that the number in the sample is significantly greater in the case of the modified methodology. This aspect is due to a considerable reduction of the doubtful cases for which the form is unable to make a reliable prediction.

• Analysing the histograms referring to not safe for use buildings the author notices, also in this case, a considerable increase in the sample size. The number is limited in the modified version too, but it is necessary to observe the trend of the intermediate histogram which results, as distribution, very close to the situation of not safe for use building that has been assumed conventionally.

• Indeed the difference between the central histograms in both distributions allow us to highlight the improvements introduced, not only in terms of reduction in the number of doubtful cases, but also for the reduced level of uncertainty in the modified version.

## 5. CONCLUSIONS

The methodology based on Fiche I, is applied to the case study of Ripabottoni, damaged by the 2002 seismic event. The first application of Fiche I permitted to make some preliminary considerations about the form's applicability to masonry built environment and to compare risk estimation to the real damage observed after a seismic event, highlighting the shortcomings of the form. A proposal for changes of evaluation factors has been defined, keeping the expeditious nature of the form.

The author has used data, which are recorded in the Fiche I but which are not counted in the evaluation of the collapse probability factor, such as the data referring the floor stiffness; this information, for example, is used in the proposal for the definition of the WG factor, which concerns the arrangement of the bracing elements in plane. In addition new parameters and corrective coefficients have been introduced, such as the masonry quality which intervenes in the definition of the WD factor; the topography factor WT; the factor that takes into account the preservation state of the building WS. A greater characterisation of some items is also proposed, which have to be detected in order to have a wider choice of factor values, while maintaining the same range of variation. After the application of the modified form to the built environment of Ripabottoni, it became clear how the modified form is able to provide better results in terms of damage scenarios. The model based on Fiche I is only the first step of the evaluation procedure adopted as a codified method in Switzerland and its aim is to define lists of priority for buildings on which to make more detailed assessments. It is a method to allocate resources for more detailed verifications and for antiseismic strengthening interventions. The WZ thresholds defined in this application can be considered representative only of masonry building similar to those of Ripabottoni and with a comparable level of seismic hazard. In fact, the WZ values change depending on type, constructive characteristics of the sample analysed and, in particular, on the basis of hazard and geomorphology of the area. The definition of the most representative WZ thresholds, is obtainable only after the retrieval of a exhaustive data sample, not only for the structural and typological characteristics of buildings, but also for the hazard level and soil characteristics.

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