Apuliabase Team

Giuseppe Monti mail: g.monti@apuliabase.com

Giuseppe Sanitate mail: g.sanitate@apuliabase.com

Leonardo Todisco mail: l.todisco@apuliabase.com

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Principi Attivi Call

Deliverable D2.4 - Summary on criteria and methodologies to evaluate the Vulnerability Index

Author: Giuseppe Sanitate

Partnerships:

Dr. Laura De Lorenzis - Università del Salento, IT

Dr. Philippe Block - ETHZ, CH

Dr. Matthew De Jong - University of Cambridge, UK

OCHSENDORF DEJONG & BLOCK LLC - Cambridge, USA

Comune di Alberobello, IT

Regione Puglia
Assessorato Politiche Giovanili
e Cittadinanza Sociale

Presidenza del Consiglio dei Ministri
Dipartimento della Gioventù
e del Servizio Civile Nazionale

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Concept of Vulnerability Index

The topic of vulnerability assessment is of major interest in Civil Engineering, with the final purpose of checking either a structure can withstand safely against the environmental forces within a certain time window.
Recently the concept of vulnerability assessment has been widely used in Italy with the aim of assessing the seismic vulnerability of strategic buildings.
The project SAVE [4], [5] - Strumenti Aggiornati per la Vulnerabilità sismica del patrimonio Edilizio e dei sistemi urbani, was the main output of GNDT - Gruppo Nazionale per la Difesa dai Terremoti, for giving suggestion about the procedure to be adopted for the estimation of the vulnerability level of existing structures.

The Apuliabase project has a slightly different purpose and wants to provide methodologies for the relative classification of heritage structures. While the project SAVE foresees the establishment of a procedure for the estimation of the structural capacity of the examined structure, the Apuliabase project provides a procedure for the classification of more case-study without taking into account their absolute structural resistance and indeed without considering the seismic action.

With this in mind, the Vulnerability Index will be based on the three indexes already presented previously:

- Durability Index - gives an idea of the damage status of the structure thanks to visual inspections and not invasive surveys;
- Static Index - gives an idea about the structural performance of the structure against gravitational loading considering the shape of the vaulted part and the permament loads;
- Seismic Index - gives an idea about the structural performance of the structure against lateral

loading.

As can be learned from the previous reports (D2.1, D2.2, D2.3), the Durability Index has an "absolute" character, in the sense that depends only on the patologies by which the structure is affected, while both the Static Index and the Seismic Index have a "relative" character because their values depend on the performance of the structure with the best capacity among all the case study.

Because of the latter reasoning and since the Vulnerability Index will eventually classify historic structures which have been exposed for centuries to the environmental forces, it is reasonable to think that the Durability Index will have a higher weight for the determination of the overall Vulnerability Index.

Calculation of Vulnerability Index

2.1 Choice of the V.I. formula

Since several information were available for each case study at this point of the project, different possibilities for the evaluation were examined:

1. Combination of Structural Durability Index (which considers I.Q.M. and only structural patologies), Static Index and Seismic Index by simply assigning weights;
2. Combination of Durability Index (which considers I.Q.M. and all the possible patologies), Static Index and Seismic Index by simply assigning weights;
3. Decreasing the Durability Index by an amount proportional to the complement to the maximum value of the Static Index and Seismic Index;
4. Decreasing the Static Index by an amount proportional to the complement to the maximum value of the Durability Index and Seismic Index

The method that seemed to give a more reasonable classification was the number 3, also because the durability aspect holds more meaning when dealing with historical structures. The several methods are summarized in the Figure 2.1 where the values of the possible Vulnebility Index (depending on the methodology used) can be read for each case study.

2.2 Estimation of the weights to be assigned to St.I and Se.I.

After the method for the calculation of the Vulnerability Index has been chosen, the "uncertainty" remains on how much decrease the Durability Index based on the values of Static Index and Seismic Index.

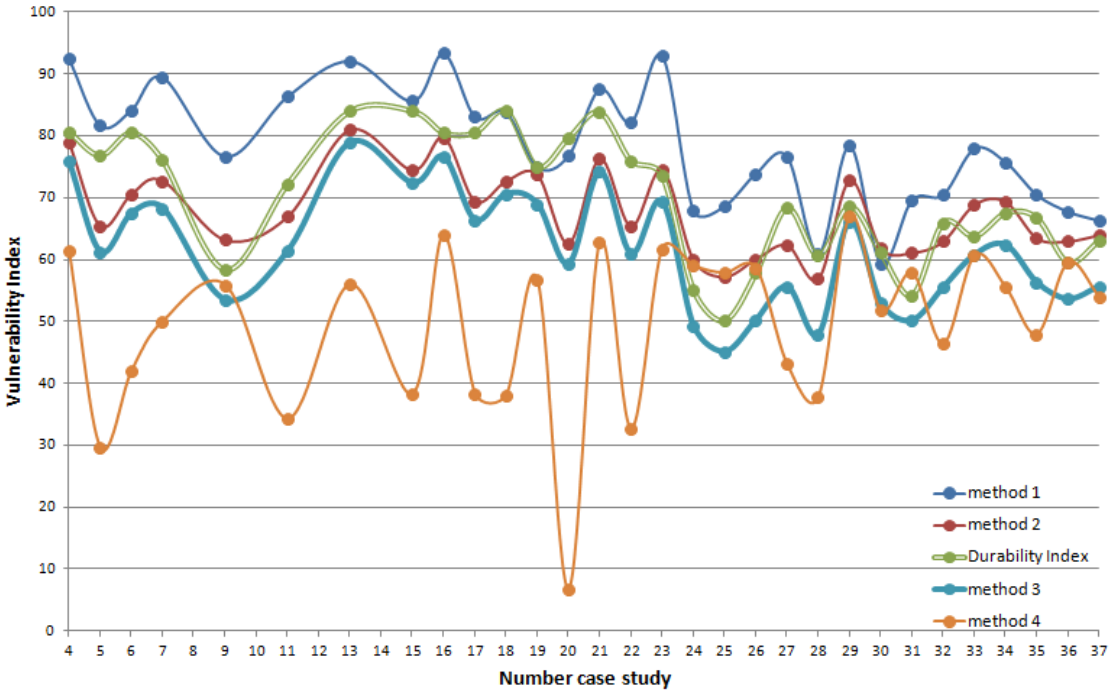

Figure 2.1: Vulnerability Index for different methods of calculation

A possible solution was deepened by looking at the probability of collapse due to respectively the static loading and the seismic loading.

2.2.1 Probability of collapse due to static loading

In particular if for the Static Index was possible to link a "critical" level of stress to the event of collapse (some sort of compressive strength) it would have been possible to find out the actual probability of collapse for each case of study depending on the value of the maximum compressive stress in the ring (see D2.2). Perhaps the actual probability could have been found by setting a statement of collapse (i.e. three rings fail) and calculating the combining probability.

Conceptually speaking the probability of collapse for a system with a certain level of Resistance and known level of Loading should be:

$$p_f = Pr(R - S < 0) = \Phi\left(-\frac{\mu_R - \mu_L}{\sqrt{\sigma_R^2 + \sigma_L^2}}\right) \tag{2.1}$$

where:

- μ_R - mean value of the compressive strength of the material;
- μ_L - mean value of the acting compressive stress;
- σ_R - dispersion of the compressive strength;
- σ_L - dispersion of the acting compressive stress;
- Φ - is a number which is tabulated and known in probability assessment.

The mean value and the dispersion for the compressive strength of the calcareous rock typical of trulli can be retrieved from a collection of data from both literature and quarry facilities [3], [2]. The mean value of the acting compressive stress can be calculated from the analysis model illustrated in D2.2. and the dispersion of this value can be estimated by looking at the stresses obtained by changing the position of the line of thrust (which is assumed to pass through the center of the masonry thickness) until a certain measure. Eventually, with some assumption, it would be possible to roughly estimate the probability of collapse sue to the static loading.

2.2.2 Probability of collapse due to seismic loading

From the seismic point of view, the probability of collapse can be directly linked to the probability of attaining a level of ground acceleration which is comparable with the collapse acceleration calculated for the structure. From the Italian code of construction - NTC 2008 [1], it is quite easy to retrieve the characteristic of the peak ground acceleration for Alberobello for different return periods. Since the return period is strictly related with the annual probability of exceedance of PGA, it is possible to retrieve the following information:

T_R	A_g (g)	Annual exceedance probability
30	0.023	0.0333
50	0.031	0.0200
72	0.036	0.0139
101	0.040	0.0099
140	0.046	0.0071
201	0.051	0.0049
475	0.064	0.0021
975	0.077	0.0010
2475	0.1	0.0004

Table 2.1: Annual exceedance probability for given values of PGA in Alberobello

The annual exceedance probability curve can be obtined easily by fitting the data collecting in the Table 2.1. The main issue is to get rid of the variable "time" for this value of probability. In fact this probability refers to 1 year period while the probability of collapse due to static loading does not depend on time, hence the two values are not comparable.

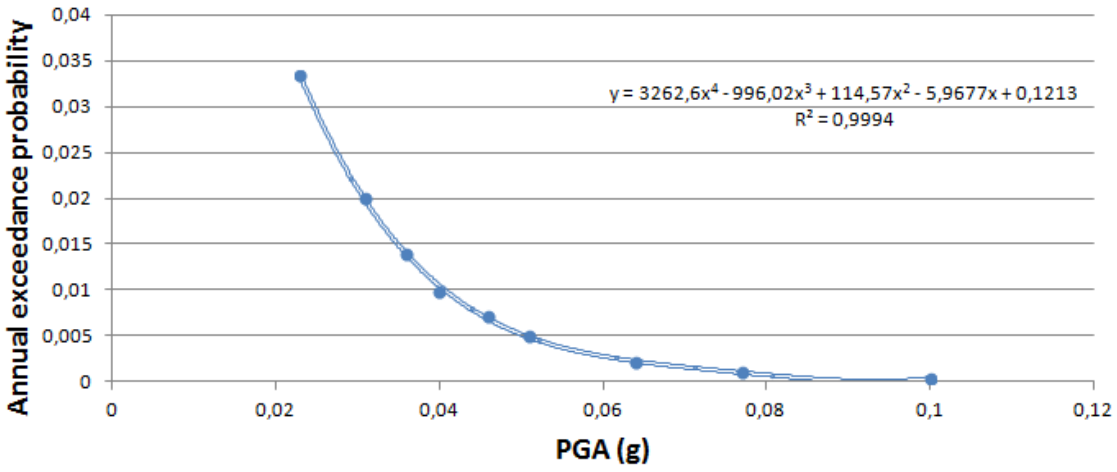

Figure 2.2: Annual exceedance probability curve in ALberobello

2.3 Combination of the Durability Index, Static Index and Seismic Index

Although, it was possible to calculate the probability of collapse due to the static and seismic loading, it was not possible to compare them in order to have a criterion to follow for giving some weights at the time of combining St.I., Se.I. and D.I. for the calculation of Vulnerability Index. The main difference between the two kind of probabilities lies on the fact that while the probability of collapse due to the static loading refers to an instantaneous event, the probability of collapse due to the seismic loading refers to an event that can actually happen during 1 year.

It is concluded that the weights to consider for the combination of the St.I and Se.I. cannot be found by a "probabilistic" procedure and should be established by empirical decision. This topic will be deepened in the follow up of the project in order to obtain a scientific methodology for the evaluation of the combining weights.

The Vulnerability Index has been calculated as:

$$V.I. = D.I. - 0.2 \cdot (max(St.I) - St.I.) - 0.1 \cdot (max(Se.I.) - Se.I) \tag{2.2}$$

The weights assigned are 0.2 for the reduction based on the Static Index and 0.1 for the reduction based on the Seismic Index.

References

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