Structural Evaluation Method For Self-made Houses In High Seismic Hazard Regions.

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ABSTRACT
San Juan village is a compilation of neighborhoods located in the center-west of Argentina. It belongs to the highest seismicity zone, according to the classification of the National Institute of Seismic Prevention, INPRES.
In this region, self-made wards have been emplaced, because of the lack of insertion of this sector in the social frame, which turns into a difficult access to official govern planes. This houses don´t respect the in force regulations INPRES-CIRSOC 103, and as a consequence, they have high seismic vulnerability.
In this paper an evaluation method based on indicators, *IVES* (Seismic Structural Vulnerability Indicator (in Spanish, *Indicador de la Vulnerabilidad Estructural asociada al Sismo*), is showed. The pondered average of every house's IVES let specify the seismic vulnerability degree. Besides, it let to highlight the constructive defects and characteristic pathologies.

Keywords: Vulnerability, Seism, Self-made houses, Evaluation

1. INTRODUCTION

San Juan village is located in Tulum Valley, province of San Juan, defined as the highest seismic hazard zone in Argentina. The province of San Juan covers zones defined as 3 and 4, in a scale that grows from 0 to 4 according to the classification of the National Institute of Seismic Prevention, INPRES.

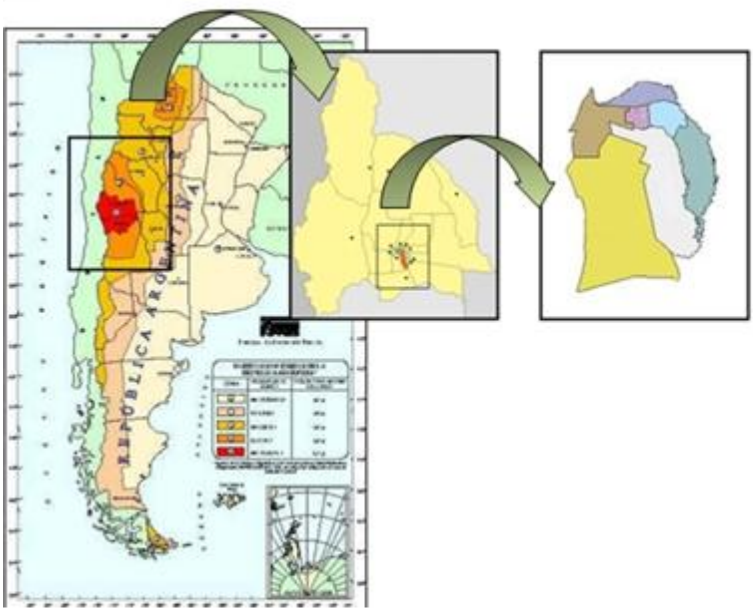

Figure 1. Location Map.

When destructive earthquakes happen, human life and property loss are significant as a consequence of buildings collapse which weren't built as to resist this kind of seismic event.
Even when in the country is in forced the seismic regulations INPRES-CIRSOC 103, there are urban areas with certain degrees of seismic vulnerability, mostly because of economic reasons, the leads to self-made buildings, without adequate materials or any seismic design. This locates this social sector in a higher vulnerability position facing the seismic phenomena expected in the region.
All the exposed before, shows a latent problem that lays beyond the regulations and the advances in the knowledge of seismic studies.
In consequence, it takes a challenge to face the problem considering the entire complex, to create methodological tools for the physic vulnerability evaluation related to seism and to propose technology solving, which can lead to give better conditions to this houses of social sectors with unsatisfied basic needs.

Figure 2. Compilation of self-buildings houses.

We're talking about increase the security of these houses' residents, reducing the seismic risk. This combines two factors, hazard and vulnerability.
The risk of a building facing a natural event is the relationship between the probability that this event actually happens and the vulnerability of the building's components. So, to value the risk is to value these two parameters.
The first stage is to know the hazard, which means the severity of the earthquake that could affect the buildings. About this, the region to study is located in the highest seismic zone in Argentine (A_A, peak acceleration=0,5g). Based on this peak acceleration, and according to the new advances in this matter, the seismic spectra can be defined so as the parameters to consider the soil influence, as a function of the shake intensity in rock and the site characteristics.
Table 1 and figure 3 show the spectra parameters for the rare earthquake in different type of soil for the highest seismic hazard zone in our country, defining so the hazard in the specific area studied.
The second stage is to study the vulnerability; this includes the expected damage and the loss that the earthquake could carry.
Of the different kinds of vulnerability that it could be analyzed in a house, for example social, urban, and physic, in this work only this last one is studied, and specifically the structural vulnerability, leaving the other aspects to later studies.

Table 1. Spectra Parameters.

Soil	Rare earthquake			
	Spectra Parameters Aa=0,525			
	Ca	Cv	T2	2,5 x Ca
A	0.280	0.280	0.400	0.700
B	0.350	0.350	0.400	0.875
C	0.350	0.455	0.520	0.875
D	0.350	0.525	0.600	0.875

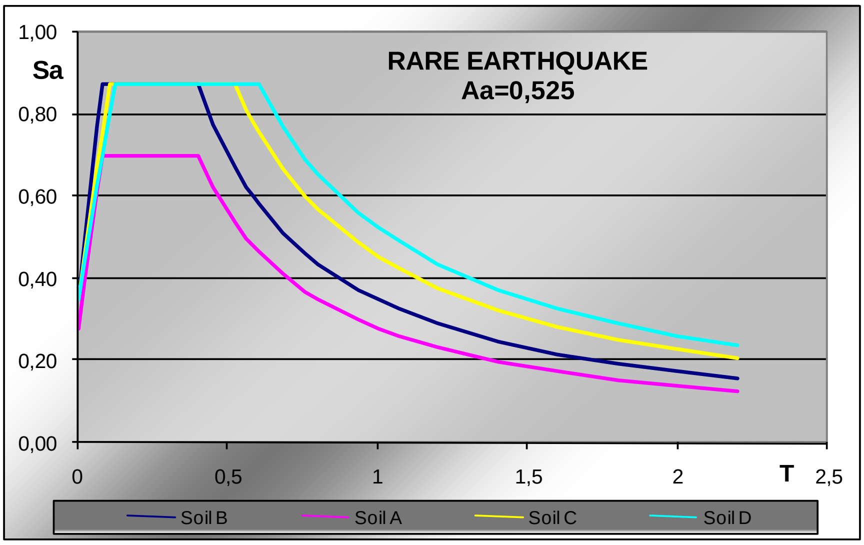

Figure 3. Rare Earthquake Spectra.

The structural vulnerability is referred to the susceptibility of damage that the components of the house that compose the lateral and vertical resistance system, could show under a destructive earthquake. It depends on various factors such as the architectural configuration, the adopted structural system, the edge of the building, the maintenance, and materials, beside others.
The building regulations in force all around the country are INPRES CIRSOC 103, which give structural considerations for a building to be considered seismic-resistant. This regulations are not suitable to analyze this existent houses, since its strict application would lead to the demolition of these, with the consequent social shock on a big number of people. Mostly because of most of these houses have "adobe" as masonry, and this material is not permitted in the considered codes.
However, there are methods to improve the behavior of buildings done with soil, developed by PUCP[1] researchers that could be applied to this problem, leading to a reduction of the collapse risk by fragile behavior. At once, these methods improve the behavior, by delaying the collapse time under an intense earthquake.

2. OBJETIVES

- Develop a methodology that permit to evaluate this buildings trending to quantify the structural vulnerability under an earthquake.
- Recognize the most vulnerable indicators that make possible to take decisions.
- Create conscience in the population trending to recognize the problem, get involved, get knowledge of the problem and be distribution agents.

3. METHODOLOGY

The methodology presented in this work is a proposal created to value the problem in a qualitative and quantitative sense, to propose technologic solutions. It was developed considering the different aspects that could have a self-made house, the characteristics and its influence in the valuation of the seismic vulnerability.
The methodology includes the following stages:

- Collection of data.
- Analysis of data.

[1] Pontificia Universidad Católica del Perú

- Evaluation of the house vulnerability and qualification of the house.
- Proposal and design of the necessary interventions.

The collection of data is done, by the inspection of the house and overturning the results on an instrument created for this, called IVES, Seismic Structural Vulnerability Indicator (in Spanish, Indicador de la Vulnerabilidad Estructural asociada al Sismo), which structure explains and fundaments in the next topic.
The data analyzing must be done in cabinet, with the results taken before, technical documentation, photos, and register of different elements of interest, such as soil data and the houses in particular. It is clear that as better has been done the stage before, better will turn out this one.
Afterwards the valuation must be done; this will be qualy-quantitative, of each general and particular indicator with the corresponding weight. With these results and thru a polynomial pondered formula the final qualification of the house is obtained.
This qualification may measure either the quality or the vulnerability of the house, as inverse variables, and pending on the use the results be needed for. In this work, the quantified vulnerability is done only for houses built with "adobe", it means, not seismic-resistant houses. The objective is to evaluate the vulnerability degree in order to propose solutions to improve their behavior.
Finally, and in function of the indicators that presents higher vulnerability, the interventions are proposed and designed to correct the fails and to improve the seismic behavior of the house.

3.1. Seismic Structural Vulnerability Indicator

The evaluation is done using the IVES, Seismic Structural Vulnerability Indicator (in Spanish, Indicador de la Vulnerabilidad Estructural asociada al Sismo), defined for this. These are designed to consider the different aspects that might have influence in the structural vulnerability and to organize these aspects in a logic way, resulting five general indicators: morphologic aspect, structural system, soil, site and pathologies, each one with particular indicator and sub-indicators as is detailed following.
The IVES, just as all instrument, are designed to reach the target they were created for. Each indicator is presented in a clear way; in order neither to demand personal decisions to the person, who must carry the data, nor to generate any ambiguity.

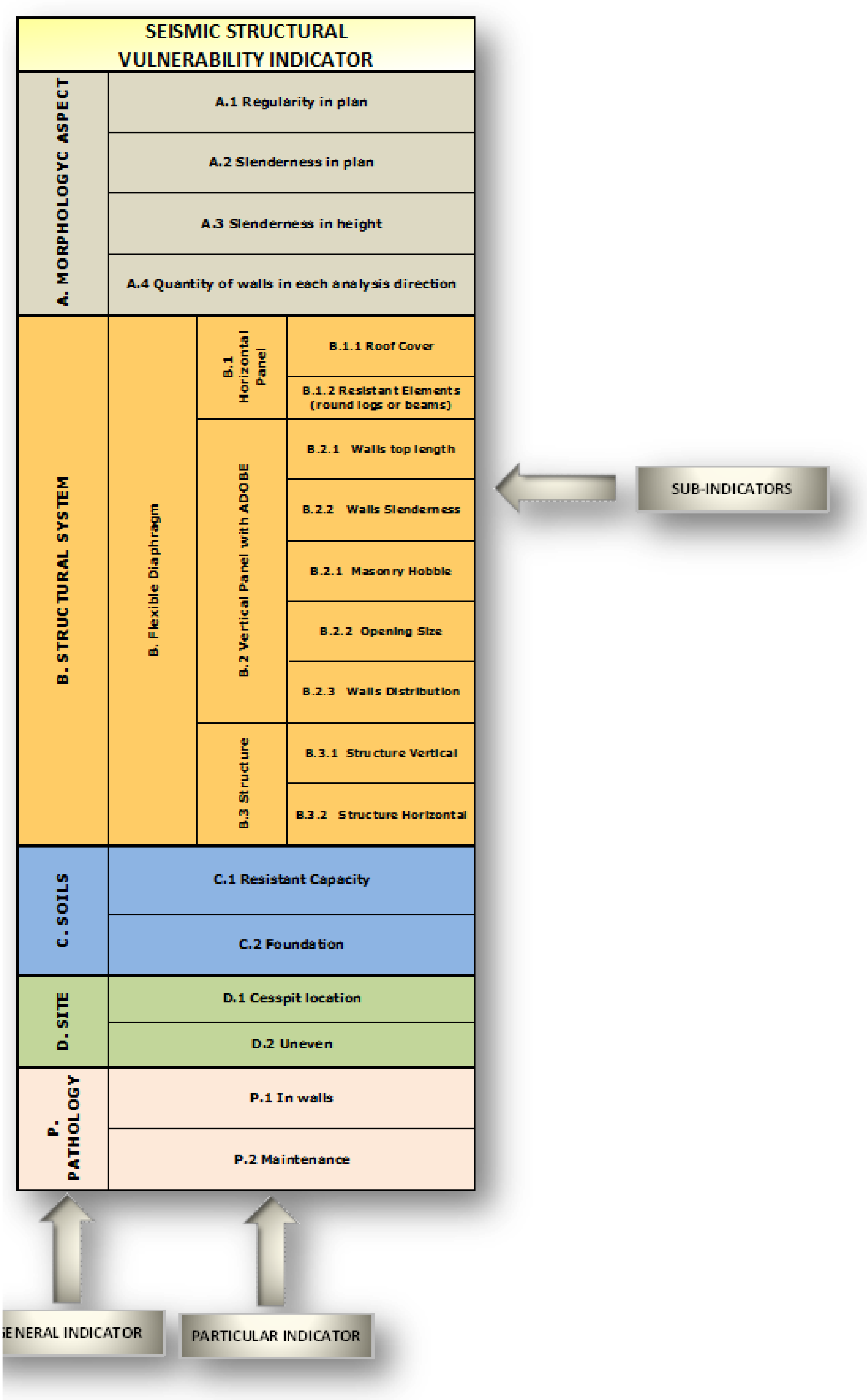

Figure 4. Seismic Structural Vulnerability Indicator.

3.1.1. Morphologic Aspects

The shape of the house is an important conditioner on the seismic behavior. It's known that the regularity in mass and stiffness distribution is essential to guarantee an adequate behavior. Complex, irregular or nonsymmetrical shapes have more complex seismic behavior, by promoting torsion, a non-desirable phenomena especially in houses built with “adobe”. The lack of uniformity generates forces concentration in some corners, which are usually difficult to dissipate, even more considering the type of building under analysis[2].

In order to evaluate all of the elements that includes the before described morphologic aspects, four particular indicators are defined:

- Regularity in Plan
- Slenderness in Plan
- Slenderness in Height
- Quantity of walls into two directions in plan.

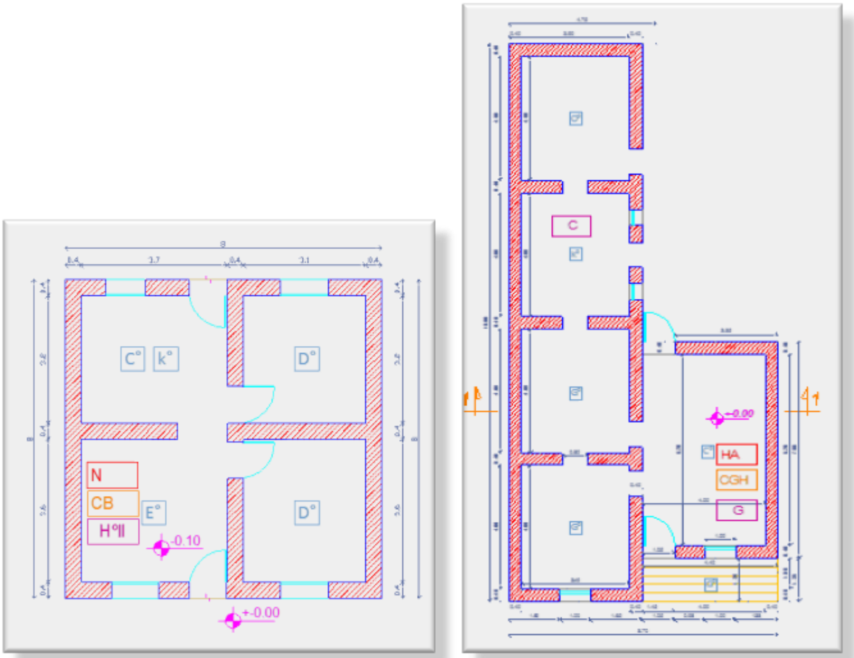

Figure 5. Morphologic Aspect.

3.1.2. Structural system

The structural system is comprised by the seismic-resistant system to vertical and horizontal loads. For the analyses, particular indicators are defined to group the resistance elements as horizontal partitions, vertical partitions and structure per se, each of which is assessed using quantifiable sub-indicators.

The “Structural System” indicator develops from the type of roof panel of the house, depending on the way of working. The analysis begins with this indicator because the characteristics of the horizontal diaphragm, whether rigid or flexible, determine a different behavior of horizontal and vertical structural elements and, thus, the requirements are also different.

Regarding the flexible diaphragm, present in adobe houses, seismic actions are determined by the influence zone due to the diaphragm incapacity to transmit loads to the different plans parallel to the seismic action. In most adobe houses the roof is made of wooden (round logs) or rectangular beams, both of which can move with respect to the other.

Considering the above mentioned to assess the house vulnerability from the construction-structural point of view, the following aspects are analyzed, grouped as particular indicators and analysis sub-indicators:

- Roof cover
- Resistant elements of the roof
- Masonry
- Vertical and Horizontal Structure

[2] SAHOP, 1977

In adobe houses the walls transmit vertical and horizontal loads to the foundations. The behavior of this type of house depends on the plant layout and the walls quantity and quality. In general, these houses lack of another structure type when facing a seismic event. Since these are the main load-bearing elements of an adobe house, the literature presents a series of empirical recommendations which have been adopted and presented as variables in the methodology, namely, size of opening, wall slenderness ratio and location, masonry unit quality and bonding[3].

Figure 6. Structural Aspect.

3.1.3. Soils

The foundation should be adequate to transmit both vertical and seismic loads to the ground. Type and dimensions of the foundation structure depend on the ground characteristics. It is important to consider this since they are generally located on inadequate grounds, in which no previous studies have been carried out. The location of the water table is also a significant factor due to soil liquefaction. Any of these situations caused by inadequate foundations will cause damage to the house, regardless of the design.

In case there is no data on the load-bearing capacity of the soil, evaluation of this indicator is carried out through the observation of differential settlements, cracking and ground vibration caused by the traffic.

3.1.4. Site features

The features of the site are also important for the vulnerability analysis because if the area is highly vulnerable to seismic events, any construction, no matter the structural system adopted, might be considered vulnerable depending on the location features.

- Cesspit location
- Uneven

3.1.5. Pathologies

Pathologies are “diseases” caused by constructive deficiencies or the presence of external non-considered agents by the time of the construction, since they might affect structural or non-structural elements (partitions) in such a way their global function is compromised.

The first indicator shows the pathologies in the house walls, such as cracks, humidity, lack of verticality, quantifying the wall proportion that shows pathologies if compared to the entire walls of the house. These are indicators that the wall integrity is compromised regarding the seismic response, reducing its collaboration to the constructive system or leading to an anticipated collapse.

In the second indicator, the global maintenance of the house, status of the roofs, facilities, plasters, etc. are assessed. Cracking and deformations of resistant elements of the roofs (round logs) mean the presence of construction pathologies generated by under sizing of the elements, increase of overload beyond admissible limits, deterioration of wooden elements due to lack of maintenance, inadequate anchoring, etc.

[3] Construcciones de Adobe Resistentes a los Terremotos. Marcial Blondet, Gladys Villa Garcia M., Svetlana Brzev.

The cause of the cracking should be determined for each case. However, regardless of the cause, it is concluded that collapse due to vertical loads only is highly probable.
Good maintenance of houses is essential to preserve the original characteristics of the construction. This assumption involves all type of constructions. Even though the construction was top quality and respect building rules, if no adequate maintenance is carried out, many of its advantages will be lost or, at least, seriously compromised.
Consequently, this indicator compromises this and the above mentioned ones, beyond its own value. This situation will be considered in the final formula for the seismic vulnerability evaluation of houses.

Figure 7. Pathologies.

Having developed several indicators affected by the structural evaluation of adobe self-made houses, the final comments provide a description of their importance. It is quite evident that the incidence of each indicator is not the same for the house behavior when facing a destructive event.
The morphological and structural aspects have greater pondering. In fact, a minimum value is demanded for each. This is reflected on the sheet form as admission test, in order to "punish" a house where these values are depressed.
Regarding the "Pathologies" indicator, it has no pondering coefficient. The pathologies compromise all the indicators beyond the result obtained in its individual analysis. Consequently, it is considered a multiplying factor of the pondered average of the remaining indicators.
When the house is under Indicators evaluation, it is carried out in a positive way, which means measuring its quality. The maximum value corresponds to compliance with the demand of the respective indicator.
Since vulnerability measures the house aspects that pose a risk under hazardous situations, it thus measures NON-compliance with the indicators. In this study, we are interested in measuring vulnerability and proposing improvements after the results have been analyzed.
Considering the above mentioned, there follows the formula that determines the percentage value of structural vulnerability when facing a seismic event:

$$IVES = \left(1 - \left(\frac{C_M * M + C_{SE} * SE + C_S * S + C_E * E}{C_M + C_{SE} + C_S + C_E}\right) * P\right) * 100 \quad (1)$$

Where:
IVES= Seismic Structural Vulnerability Indicator (in Spanish, Indicador de la Vulnerabilidad Estructural asociada al Sismo)
CM= Pondering Coefficient of the Morphological Aspect Indicator (in Spanish, Coeficiente de Ponderación del Indicador Aspecto Morfológico)
CSE= Pondering Coefficient of the Structural System Indicator (in Spanish, Coeficiente de

Ponderación del Indicador Sistema Estructural)
CS= Pondering Coefficient of the Soil Indicator (in Spanish, Coeficiente de Ponderación del Indicador Suelo)
CE= Pondering Coefficient of the Site Features Indicator (in Spanish, Coeficiente de Ponderación del Indicador Entorno)
M= Value of the Morphological Aspect Indicator (in Spanish, Valor del Indicador Aspecto Morfológico)
SE= Value of the Structural System Indicator (in Spanish, Valor del Indicador Sistema Estructural)
S= Value of the Soil Indicator (in Spanish, Valor del Indicador Suelo)
E= Value of the Site Features Indicator (in Spanish, Valor del Indicador Entorno)
P= Value of the Pathologies Indicator (in Spanish, Valor del Indicador Patologías)
There follows a definition for the ranges of the qualitative evaluation:
If the IVES value is greater than 60%, the house is considered to be Highly Vulnerable (in Spanish, V.A.) when facing a seismic event.
If the IVES value is smaller than 40%, the house Vulnerability is Low (in Spanish, V.B.) when facing a seismic event.
If the IVES value is between the two previous values, the Vulnerability of the house is Mid (V.M.) when facing a seismic event.

The methodology developed lets us determine not only the quantitative and qualitative house vulnerability but also condenses briefly and detailed information in a sheet form stating the problems of each house. In addition, these are necessary elements to carry out the last stage proposed, which is the development of improvement alternatives that guarantee better behavior when facing severe seismic events. Proposed reparation techniques should be technically viable and economically possible.

4. CONCLUSIONS

The word evaluation has been widely spread throughout the modern world, thus assuming that to assess is to measure. Hence, it is important to know what, how, who, when, why and what for something is measured. At this stage, quality indicators and sub-indicators came into action and as seen before, they are closely related.
In seismic zones, house vulnerability evaluation is quite important since it favors quick measurements which will yield a risk decrease. To decrease the risk means decreasing not only material damage but the risk of losing human lives. Consequently, all possible measures to consider must be approached properly and in time.
Considering the above mentioned, we should reflect on the importance of evaluation since it lets us carry out adequate actions, avoiding unnecessary risks as a result of an improvised decision.
Regarding the methodology presented, we conclude that:

- It is easily applicable and processed.
- The data collection stage can be carried out by persons, who should be duly trained on the issue.
- It lets us visualize quickly several analysis variables to consider for seismic vulnerability evaluation.
- No matter the material or system adopted, it highlights weak points in construction, thus favoring the design of improvements.
- It favors the definition of design and construction guidelines to improve adobe constructions built.
- It lets us work with community members, engaging the interested parties during the investigative process, involving them and raising awareness on the issue and its treatment.
- The analysis of the cost-benefit relationship should be also considered during the evaluation that is to say, a balance between the quality of the results expected and the costs of the investment required.

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