



CONSEQUENCES OF GENDER INEQUALITY IN THE FACE OF EARTHQUAKE DISASTERS

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Abstract

Research on the exposure of women to several types of natural hazards has shown that gender inequality may increase their risk of being negatively affected. For instance, in the developing world, people living below the poverty line face the greatest exposure to natural hazards; seventy percent of people living in this condition are women. Moreover, several of them are housewives in charge of household chores and raising children. This makes the impact of disasters not gender neutral as their dwellings tend to be highly vulnerable to natural hazards, and women spend more time at home than men. This paper is oriented to analyze the consequences of these facts in the face of potential disasters produced by earthquakes in Colombia. To do so, several earthquake scenarios are simulated by considering the uncertainties related to modelling exposure and seismic hazard in vulnerable urban environments. To quantify how much longer women stay in vulnerable dwellings than men, the results of a survey carried out in 2017 by the National Administrative Department of Statistics (DANE) on the general use of time of Colombian citizens are analyzed. In particular, data on household activities are of greatest interest for this research. Forecasts show that in case of a catastrophe produced by an earthquake, women have a higher probability of being negatively affected than men.

Keywords: Gender inequality, social vulnerability, seismic risk scenarios



1. Introduction

Seismic risk mainly depends on the capacity of civil infrastructure to withstand ground motions produced by earthquakes. Current strategies to mitigate this inherent risk to society are oriented to develop design methodologies for new structures and to quantify the expected performance of existing ones. In turn, innovative technologies are developed day by day to improve this performance. KaIROS project [1] is aimed at maintaining and increasing the resilience and sustainability of communities against earthquakes. The main objective of this project is to improve the assessment strategies for quantifying seismic risk at urban level. Several computational tools, which are used in this article, have been developed to this end.

Depending on the size of an earthquake, and the proximity to human settlements, civil structures can be seriously affected. In this respect, due to world population growth, which exhibits higher rates in low-income regions, in a short time, there will hardly be a place where a moderate- to high-magnitude earthquake can occur without affecting society. In addition, increasing globalization has produced a redistribution of the risks to the entire society. For instance, a couple of decades ago, negative consequences of catastrophes barely affected other areas than the stricken ones. Because of immigration and commercial activities between countries, nowadays, this can no longer be affirmed. For all these reasons, current risk of seismic disasters is higher than at any previous time, and if no proper measures are taken, it will continue increasing [2]. Its extreme consequence for humankind is the collapse of civil structures since this leads to the loss of lives. Not to mention that economical losses can reach the point of affecting the sustainable development of entire countries. Such socio-economical setbacks trigger poverty, inequality, casualties, amongst many other negative consequences. This should be a concern of the whole society and not only of the areas with high seismic hazard.

This paper is oriented to quantify the consequences of gender inequalities in the context of seismic risk. There are two main facts on which this study is based: i) an important amount of people living below the poverty threshold are women, [3]; ii) in certain places, women living in vulnerable urban areas stay in their homes longer than men. Evidence on the latter can be found in a survey conducted by the National Administrative Department of Statistics in Colombia (DANE by its acronym in Spanish) aimed at quantifying the amount of time spent on daily activities by Colombian citizens [4]. This may mean that people's expected risk from natural disasters is not gender neutral. Actually, this tendency is confirmed after analyzing the gender distribution of the people affected in Colombia by an earthquake that occurred in Armenia in 1999 [5].

In order to verify this unbalance in the seismic risk, probabilistic earthquake scenarios [6] based on the aforementioned facts have been simulated. Fragility functions for the structural typology unreinforced masonry of mid-height, URMM, have been derived to perform these calculations. Cloud analysis has been employed to do so [7]. It is worth mentioning that in spite of its high seismic vulnerability, this structural typology is very frequent in several urban environments in Colombia, even in areas where seismic hazard can be considered moderate-to-high.

Based on the calculated fragility functions, the Hazus' methodology to estimate injuries has been employed. Then, using data coming from the time spent on daily activities [4], the number of affected people is estimated by gender. The results show that in the event of an earthquake disaster, women are at higher risk of being adversely affected than men.

2. Time spent on daily activities

Historically, women have fulfilled the role of caregivers within the home. Nowadays, in several places across the planet, they are still in charge of a large part of domestic activities related to cleaning, food preparation, childcare, amongst many other activities that are not economically remunerated. Performing these activities does not allow many of them to have enough time to generate their own income or develop professionally. Furthermore, women living in low-income regions may be disproportionately affected by this unbalance. This is because their homes are generally at high-risk in front of natural disasters, and they remain more time at home than men. In this respect, between 2016 and 2017, DANE conducted a survey of people from 44,999 households, which sought to collect information related to the formation of households, type of housing and the number of people who lived in them [4]. As an added value to this survey, people were asked about the



time spent on housework, personal care, passive and other unpaid care. This questionnaire was designed in this way to get people's opinion on gender roles.

This survey was conducted taking into account various regions of the country. Thus, the results were classified according to each region. In general, it was observed that women spend more time in domestic activities than men. In the present study, the central region of Colombia was taken as a reference to perform the analysis. The unpaid domestic activities have been used to determine the time spent at home of citizens in this area. The following activities have been considered:

- A1. Food supply
- A2. Wardrobe maintenance
- A3. Home cleaning and maintenance
- A4. Activities with children under 5 years of age
- A5. Physical care for people at home
- A6. Support for household members
- A7. Personal care, including sleep

The average time invested in each of these activities can be seen in Table 1. Accordingly, women spend about 1.2 times more time at home than men. As commented above, this unbalance has consequences on the seismic risk estimation.

Table 1 Time dedicated to activities carried out at home

Central Region			
Activities	Men (minutes)	Women (minutes)	Dedication ratio (W/M)
A1	61	131	2.15
A2	45	72	1.60
A3	70	96	1.37
A4	85	94	1.11
A5	38	76	2.00
A6	65	82	1.26
A7	641	651	1.02
Total (min)	1005	1202	1.20
Total (hours)	16.75	20.03	

2. Characterization of the exposure

Most of the masonry construction around the world is based on unconfined masonry. Structural typologies using this kind of elements are highly vulnerable [8]. In this article, the structural behavior of URMM will be used as testbed. This typology has been and continues to be a dangerous solution to meet the need for affordable housing in the developing world, even in areas with moderate-to-high seismic hazard. Historically, inhabitants of other countries in the world have also used this typology, with the consequent increase in seismic risk [9]. It is worth mentioning that inhabitants involuntarily increase this vulnerability by making inappropriate changes in their homes. These modifications are generally to augment the size of the dwelling.

In order to quantify the main physical features of this typology, use is made of the Hazus Technical Manual [10]. Accordingly, its mean fundamental period has been estimated as 0.5 sec. Because of the probabilistic nature of the dynamic properties of structures, this value has been used to simulate structural models with random properties. Specifically, it has been assumed that the mean fundamental period of the simulated structures follows a continuous uniform distribution in the interval (0.4-0.6) sec.



3. Seismic hazard characterization

Seismic risk has been quantified in an event-to-event basis. To do so, fragility functions based on the cloud analysis have been derived [7]. This methodology requires obtaining pairs of points that represent the seismic hazard (intensity measures, IM) and the structural response (engineering demand parameters, EDP). In this research, these points have been obtained through time-history analysis. Consequently, seismic hazard has been characterized by using ground motion records.

Depending on the risk assessment approach, there are several methodologies to select ground motions [11]. Typically, the goal is to have enough ground motion records that lead the structure to different performance levels. However, the availability of strong ground motion records with high values of the conditioning IM is a common restriction found in current databases. This may trigger excessive scaling that can introduce bias in the structural response [12]. In order to mitigate such issues when employing cloud analysis, the following procedure has been used for selecting and scaling (where necessary) ground motion records:

1. Selection of the database
2. Identification of the IM
3. For each record of the database, calculation of the identified IM
4. Definition of IM intervals
5. Per each interval, selection of a number of records whose IM values belongs to the interval
6. If an interval does not contain enough records, an appropriate number of them is selected and scaled from the previous interval; this criterion is meant to avoid excessive scaling

The engineering strong motion database has been employed to select ground motion records [13]. Identifying the IM (step 2) mainly depends on its efficiency and sufficiency [14]. The spectral acceleration at the fundamental period, $Sa(T_1)$, has been one of the most used IMs. However, this IM has been questioned due to its low capacity to explain the non-linear dynamic response of systems [15]. Instead, an IM based on the geometric mean of spectral acceleration values estimated at periods covering both higher and elongated modes of response, Sa_{avg} , is more efficiency and sufficiency than $Sa(T_1)$ [16-18]. Analogous to this concept, an IM identified as AvSa is considered herein to perform the analysis. AvSa differs from Sa_{avg} since it is calculated using the arithmetic instead of the geometric mean. However, it is important to note that AvSa is calculated from the geometric mean of the horizontal spectra. It is worth mentioning that the period range for averaging the spectral ordinates of the IM should be established from the dynamic properties of the entire population of buildings [19]. Accordingly, this range has been set at (0.22-0.83) sec. The intensity levels defining the upper and lower limits of each band (step 4) range from 0.2 to 2.0 g at intervals of 0.2 g (i.e., 10 bands have been defined). Thus, the horizontal components of 100 ground motion records (10 per band) have been obtained from the seismic database. Fig. 1 shows the geometric mean spectra of these records.

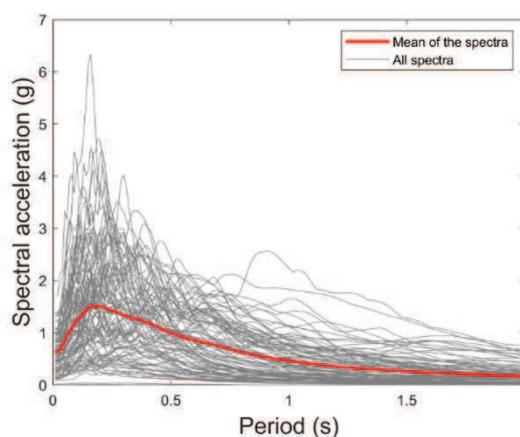


Fig. 1 Geometric mean spectra of the selected ground motion records



4. Structural modelling

4.1 Engineering demand parameters extracted from single degree of freedom systems

In order to analyse the expected damage of buildings, it is necessary to consider several sources of uncertainty. However, the higher the complexity of the structural model, the higher the computational time to extract reliable information from it. Thus, simplifying the structural model significantly diminishes the computational effort, allowing analysing several building models in a fraction of time. In this sense, one of the most simplified representation of a building is an SDoF system. This model has been extensively used to estimate the dynamic response of civil structures [20]. It allows calculating time-history responses in an easy way, given a determined fundamental period and damping. However, the response of a single SDoF does not consider neither the stiffness' loss because of plastic damage nor the participation of higher modes. When estimating engineering demand parameters, EDPs, these shortcomings have been addressed by averaging spectral quantities around the fundamental period of the building model. Analogous to this, it is proposed to approximate the dynamic response of a building in each direction by averaging the time history response of a set of SDoF systems in the interval $(0.5T_n, 1.5T_n)$. To do so, it has been used the dynamic equilibrium equation for SDoF systems:

$$m\ddot{u}(t) + c\dot{u}(t) + ku(t) = -m\ddot{u}_g(t) \quad \text{Eq. 1}$$

where $\ddot{u}(t)$, $\dot{u}(t)$ and $u(t)$ are the spectral acceleration, velocity and displacement time history responses of the SDoF, respectively; $\ddot{u}_g(t)$ is the acceleration ground motion; m , c , and k represent the mass, damping and stiffness of the system, respectively. Thus, the spectral time history response of a building can be estimated as follows:

$$\ddot{u}_n(t) = \frac{1}{p} \sum_{i=1}^p \ddot{u}(t, T_i) \quad \text{Eq. 2}$$

$$\dot{u}_n(t) = \frac{1}{p} \sum_{i=1}^p \dot{u}(t, T_i) \quad \text{Eq. 3}$$

$$u_n(t) = \frac{1}{p} \sum_{i=1}^p u(t, T_i) \quad \text{Eq. 4}$$

n represents the direction of the response (x or y), T_i are the components of a vector of periods within the interval $(0.5T_x, 1.5T_x)$ for the x and $(0.5T_y, 1.5T_y)$ for the y directions. In this way, the 3D spectral time history response of the simulated system has been estimated as follows:

$$\ddot{u}_{(x,y)} = \sqrt{\ddot{u}_x^2 + \ddot{u}_y^2} \quad \text{Eq. 5}$$

$$\dot{u}_{(x,y)} = \sqrt{\dot{u}_x^2 + \dot{u}_y^2} \quad \text{Eq. 6}$$

$$u_{(x,y)} = \sqrt{u_x^2 + u_y^2} \quad \text{Eq. 7}$$

4.2 Global drift as EDP

The global drift of a structure, GD , is an EDP highly used in estimations of the seismic risk using the capacity spectrum method [21]. Herein, GD is estimated according to the following equation:



$$GD = PF_1 \frac{\max(u_{(x,y)})}{h_{eq}} \quad \text{Eq. 8}$$

where PF_1 is the load participation factor [22]; h_{eq} is the equivalent height of the building. For the sake of simplicity, PF_1 has been fixed to 1.33 as recommended in [10]. h_{eq} has been estimated as a function of T_{XY} ($h_{eq} = 13,7 * T_{XY}$); it has been assumed that the mean height of the analysed typology is 6.85 m. Thus, set of IM-EDP pairs are obtained to derive fragility functions according to the following procedure:

1. Generate a uniform random sample within the interval [0.4 0.6] sec. This sample represents the fundamental period of an URMM structure in the x direction, T_x
2. Calculate T_y as a random fraction of T_x . The random fraction is obtained as a uniform random sample varying within the interval [0.75 1]
3. Given one T_x - T_y pair and one ground motion record randomly selected from the entire set, GD is estimated (see Eq. 8)
4. Repeat step 1 to 3 until having one-thousand IM-EDP pairs

Fig. 2 shows one-thousand IM-EDP pairs according to the procedure described above.

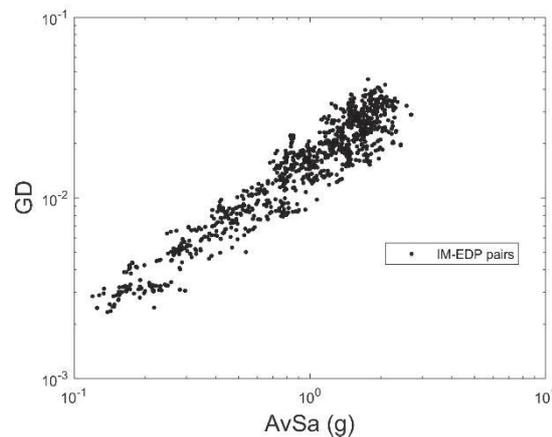


Fig. 2 IM-EDP pairs for URMM building models

4.3 Fragility functions

From a set of IM-EDP pairs, one could derive fragility functions according to the so-called ‘cloud analysis’ approach [7]. This methodology requires to calculate the best fit curve between a set of IM and EDP realizations in the log-log space. The resultant curve is used to estimate the mean value of a parametric statistical distribution, given an IM value. The variability of this parametric distribution ($S_{y/x}$) is estimated as the standard deviation of the IM-EDP residuals with respect to the fitted curve. In this way, the probability of exceeding a certain damage threshold can be calculated. These thresholds are realizations of the engineering demand parameter under consideration, EDP_C . In this study, the damage threshold values for URMM provided by Hazus 99 [10] are used (see Table 2).

Table 2 Damage threshold for URMM according to Hazus 99 [10]

	Slight	Moderate	Severe	Complete
Damage threshold	0.0016	0.0032	0.008	0.0187

Note that the damage thresholds presented in Table 2 are related to the maximum inter-storey drift ratio, MIDR. However, this EDP is generally higher than GD. In order to cover this issue, the probabilistic seismic response of three-hundred multi-degree-of-freedom systems, MDoF, representing structures of 3, 4 and 5 storeys have



been calculated. The ground motion records selected above have been used to do so. From these analyses, GD and MIDR have been calculated and a relationship between both variables has been derived (see Fig. 3).

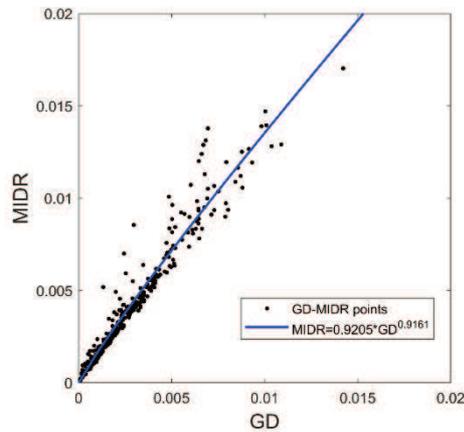


Fig. 3 Relationship between GD and MIDR using MDoF systems

In this way, GD values obtained by using Eq. 8 can be transformed into MIDR values. After this transformation, fragility functions presented in Fig. 4 have been derived by considering the damage thresholds shown in Table 2.

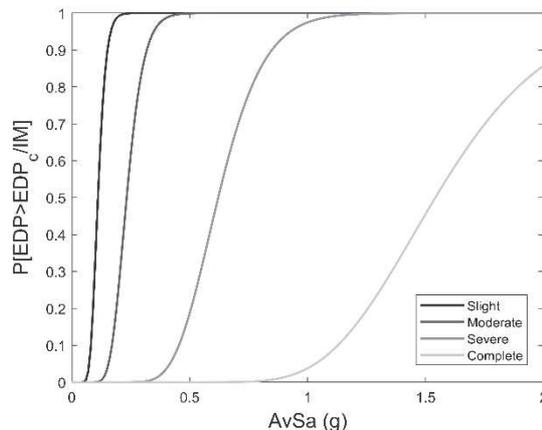


Fig. 4 Fragility functions for URMM buildings

5. Earthquake scenarios

5.1. Armenia's Earthquake

On January 25, 1999 at 13:19 pm there was a strong earthquake of magnitude 6.1 Mw, which released a significant amount of energy that seriously affected the infrastructure of the area and compromised the safety of the surrounding inhabitants. According to the DANE's report [5], it was quantified a total of 1,185 casualties, 8,536 injured, 35,972 houses were destroyed or uninhabitable (several of them were URMM buildings) and 4,467 houses were partially affected. Out of the total number of casualties during the catastrophe, 78% were concentrated within the city of Armenia.

The city of Armenia by the year 1999 had a total of 214,388 inhabitants, of which 101,166 were men and 113,222 were women. During the emergency, a total of 921 casualties and 383 disappeared were reported. In the case of men, a total of 445 casualties and 128 disappearances were informed, while on the women's side these numbers were 476 casualties and 255 disappearances. The most intense ground motion was recorded at the Cordoba station; Fig. 5 shows the acceleration spectra of the E-W and N-S components of this record.

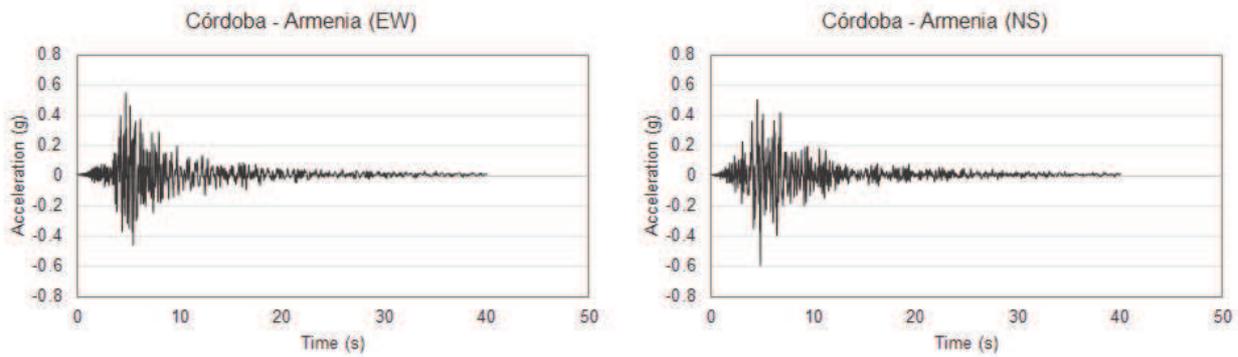


Fig. 5 Horizontal ground motion recorded at the Cordoba station

Table 3 shows the parameters associated to the rupture of the analysed earthquake.

Table 3 Earthquake parameters of the Armenia's earthquake

Event	Year	Station	Mag	R_{jb} (km)	Geology
Córdoba, Colombia	1999	Armenia	6,3	13,4	Rock

Fig. 6 shows the response spectra of the horizontal components of the ground motion records as well as the current uniform hazard spectrum, UHS, for return periods equal to 475 and 2475 years for this city [23]. It is possible to observe how the event far exceeded the UHS for design (i.e. return period equal to 475 years). However, it is more similar to the seismic hazard associated with a return period equal to 2475 years.

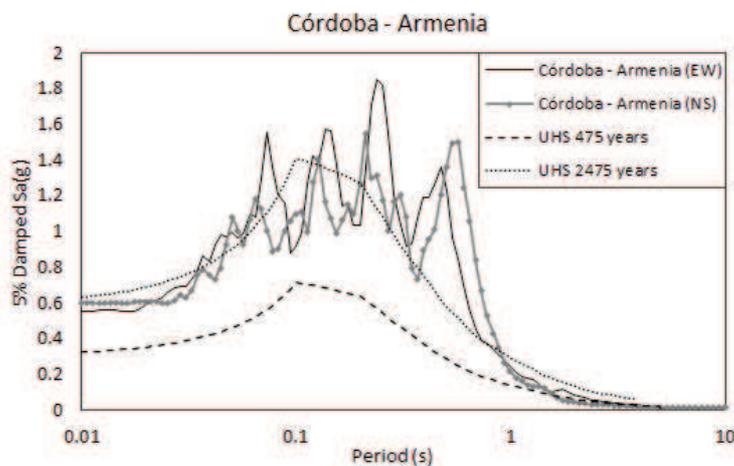


Fig. 6 Spectra of the selected ground motions and uniform hazard spectra (UHS) for the analysed area

Considering the mean fundamental period of the analyzed typology, i.e. $T_{XY} = 0.5$ sec, A_{vSa} is 0.944 g for this record. This IM value will be used to simulate one-thousand earthquake scenarios. Specifically, it will be assumed that A_{vSa} follows a lognormal distribution whose mean value is 0.944 g with a coefficient of variation equal to 0.1 (see Fig. 7).

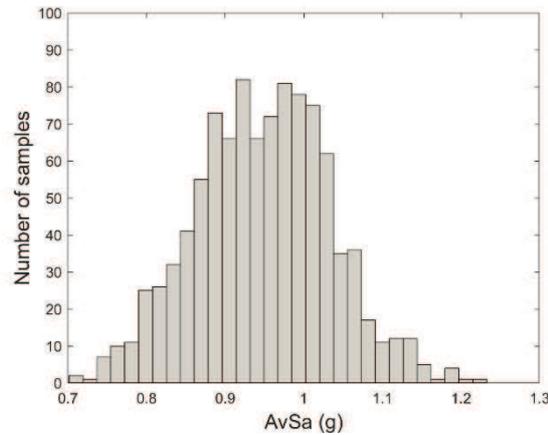
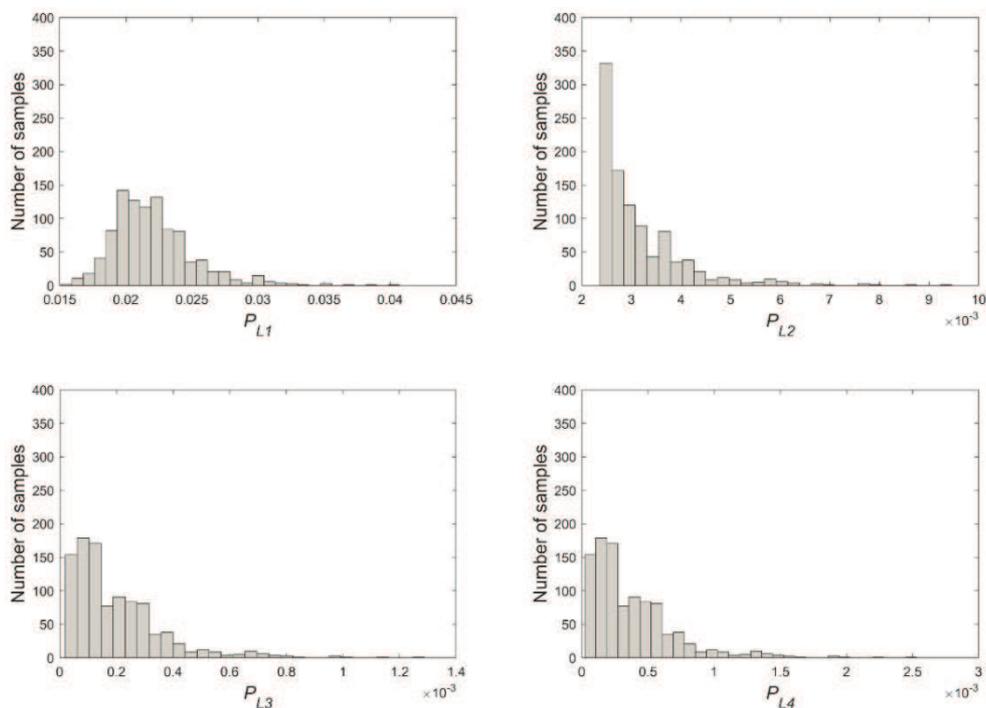


Fig. 7 Simulated AvSa values

5.2. Estimation of the number of people injured

The methodology presented in Hazus 99 to estimate injuries has been applied in this article [10]. Specifically, the indoor casualty rates (see Tables 13.3-8 of Hazus 99) has been used to estimate the probability of suffering a certain injury severity level. This methodology requires the estimation of the probability of occurrence of each damage state given an earthquake scenario. These probabilities have been calculated from the fragility functions presented in Fig. 4, given the simulated intensity levels (see Fig. 7). Based on these values, the probability of suffering injury severity level i , $P_{Li,j}$, in the scenario j , has been estimated according to Hazus 99 (see Fig. 8).

Fig. 8 Probability of suffering an injury severity level i

Then, using values provided by Table 1, it has been possible to calculate by gender the number of affected people suffering a specific injury severity level i , $N_{ILi,j}$, in the scenario j . To do so, the following equation has been employed:



$$N_{ILi,j} = P_{Li,j} * P_{g_j} * P_{h_j} * N_p \quad \text{Eq. 9}$$

where $N_{ILi,j}$ represents the number of affected people in each simulated scenario; $P_{Li,j}$ is the probability of suffering injury level i (see Fig. 8); P_{g_j} is the probability of being women or men; P_{h_j} represents the probability of being at home (see Table 1); and N_p is the number of people considered in the analysis. For the sake of simplicity, this number has been assumed as 100 000. Regarding P_{g_j} , the last cadastral census carried out in Colombia indicated that the percentage of women is 51.2% and of men 48.8%. No bias has been assumed for this estimation (i.e. P_{g_j} is the same for all scenarios). To account for bias in the statistical estimation of P_{h_j} , it has been assumed that values presented in Table 1 are the mean ones of a Gaussian distribution with a coefficient of variation equal to 0.05. Thus, one-thousand samples were simulated and substituted in Eq. 9 for estimating the number of affected people according to the injury severity levels presented in Hazus 99.

Fig. 9 shows the histograms of the expected number of affected people classified by gender according to the scenarios described above; median values are presented in Table 4. These scenarios clearly confirm the unbalance in risk by gender.

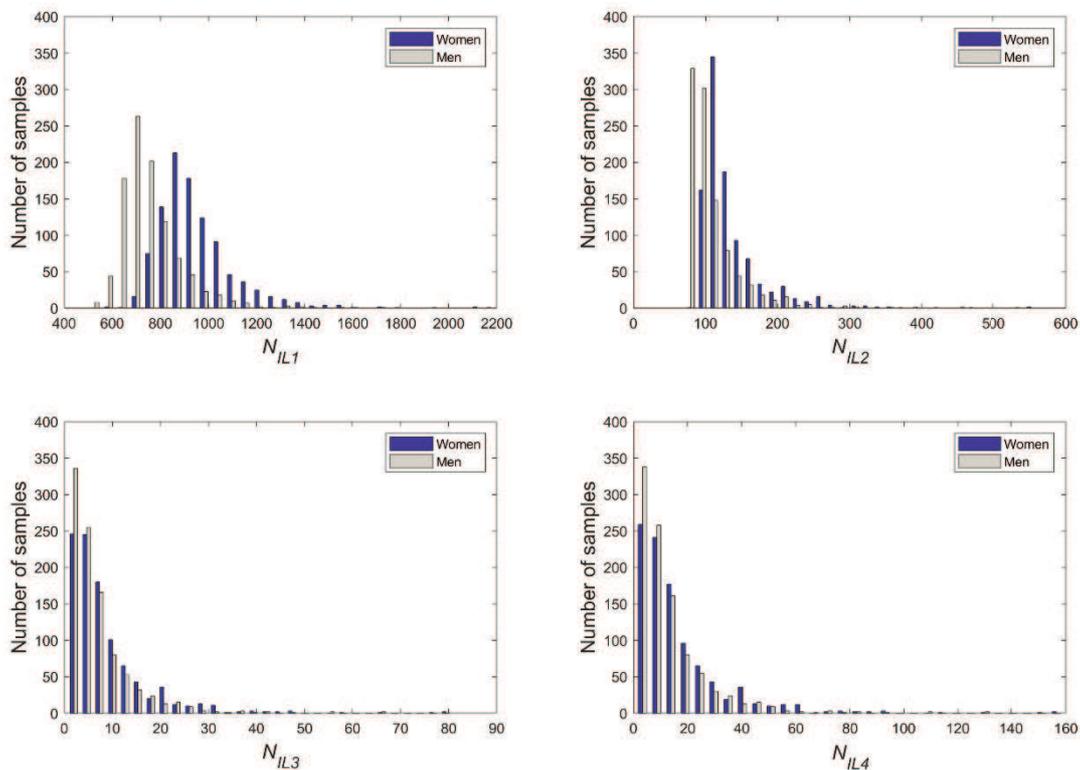


Fig. 9 Number of people suffering an injury severity level i . The values presented are per 100 000 people

Table 4 Median values, $\mu_{N_{ILi}}$

	$\mu_{N_{IL1}}$	$\mu_{N_{IL2}}$	$\mu_{N_{IL3}}$	$\mu_{N_{IL4}}$
Women	926,5	121,9	6,4	11,8
Men	737.6	97.4	5.1	9.6

6. Conclusions

In this article has been presented a quantification by gender of the risk to injury in front of catastrophes by earthquakes. The outcomes of a survey performed in Colombia regarding the use of the time revealed that Colombian's women spend more time at home than men because of house chores. The purpose of the present study has been to give a better visualization of the role of women within the Colombian household and how



taking over most of the unpaid work increases their risk, especially if the dwellings in which they stay do not meet the necessary protection measures to withstand the effects of natural disasters.

Analysing data from a catastrophic event that occurred in a city in Colombia, Armenia, it is possible to observe the tendency of women to be more affected than men [5]. This could be explained because more women than men lived in the affected places, but it should be borne in mind that this can also be a consequence of gender inequality. Note that if the ratio between the number of women and men that lived in the surveyed regions is calculated (1.11) and compared with the ratio of the number of women and men killed or missing as a result of the disaster (1.28), it can be concluded that the cause of the unbalanced risk was not only due to the higher number of women in the area. It can also be attributed to inequality in the distribution of roles with respect to gender. These data have been confirmed by the simulation of earthquake scenarios performed in this research. Although they represent the central region of Colombia, the data observed for other regions point to the same conclusion.

It has been considered a highly vulnerable structural typology to perform the simulations (URMM). In spite of the high vulnerability of this typology, it is present in most of the countries of the world. Actually, several catastrophes related to earthquakes worldwide can be associated to the use of this vulnerable typology. In this respect, it is worth mentioning that sometimes inhabitants involuntary increase the vulnerability of their dwelling by performing inadequate modifications. Therefore, it is very important to easily communicate the potential consequences of these actions to the non-specialized community. It is also a means of getting politicians and decision-makers to propose new laws aimed at improving the resilience of civil infrastructure.

In general, it is of utmost importance to mitigate the seismic risk associated with vulnerable typologies, otherwise, the achievement of several sustainable development goals can be compromised [24]. According to the results presented in this study, increasing the performance of vulnerable typologies, especially in low-income regions, can be a direct action to mitigate gender inequalities. It is also important to develop improved social strategies to empower women, not only because of the injustice inherent in gender inequality, but also as a measure to protect the population most at risk, in this case, themselves.

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