Collecting and Managing Building Data to Perform Seismic Risk Assessment – Palestine Case Study

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Abstract. This paper describes a web interface with GIS functionality (Web-GIS) that Eucentre (EUropean CENtre for Training and Research in Earthquake engineering) developed for SASPARM 2.0 (Support Action for Strengthening PAlestine capabilities for seismic Risk Mitigation) project [1].

The SASPARM 2.0 WebGIS is a simple and intuitive platform intended for people with different backgrounds, such as citizens, students, practitioners, governmental and non-governmental institutions. The final aim of the implemented WebGIS application is to calculate the seismic risk of residential buildings. Nablus has been taken as case study to demonstrate, implement, and calibrate project actions. To calculate the seismic risk, residential buildings data are collected. Such activity can be conducted by both practitioners and citizens who compile two standard forms that differ from each other only in terms of detail. The survey forms can be compiled directly on WebGIS, at the dedicated tabs, or through two mobile apps designed for the purpose. All filled forms are shown on the homepage map of the WebGIS platform. Starting from the collected data, the seismic risk of each single building is evaluated by combining the hazard and the vulnerability with its exposure. In particular, the seismic demand to which each building is subjected to is defined from the hazard curve. In the specific case study of Nablus, the hazard curve is obtained by referring to "West Bank and Gaza Strip: Seismic Hazard Map Distribution". The structural vulnerability, instead, is quantified through fragility curves calculated with the mechanical method SP-BELA (Simplified Pushover-Based Earthquake Loss Assessment), modified to represent the building environment of Nablus.

Keywords: Vulnerability assessment · Seismic risk · WebGIS platform · Mobile app

1 Introduction

The seismic risk is defined by the combination of three different factors:

- hazard, i.e. the probability of occurrence of an earthquake exceeding a certain threshold of intensity magnitude (i.e. PGA) in a given area and in a certain interval of time;
- exposure, i.e. the importance of the object exposed to the risk;
- vulnerability, i.e. the level of damage that a structure can suffer when subjected to an earthquake of a certain level of intensity.

It is evident that to reduce the seismic risk it is necessary to intervene on the vulnerability. This awareness underlined the importance of a new Palestinian design code, introduced at the end of SASPARM (Support Action for Strengthening Palestinian-administrated Areas capabilities for seismic Risk Mitigation) project [2] which is a project financed in October 2012 within a FP7 framework with the aim to spread the concept of seismic risk in Palestine. The second aspect is the need for an assessment of the seismic vulnerability of buildings. This activity has been conducted in SASPARM 2.0 project [1], founded in a DG ECHO framework, where a methodology of four different steps has been carried out.

The first step consisted in the identification of the most common structural types in Palestine. From the survey activities, it has been evident that Palestinian buildings can be classified in four main categories: i.e. reinforced concrete frame buildings, reinforced concrete soft storey buildings (*pilotis*), reinforced concrete shear wall buildings and masonry buildings. Reinforced concrete buildings generally exceed ten floors and have various uses. On the contrary, masonry structures have not more than four floors and are used predominantly as residential buildings.

After the definition of the structural type, survey forms have been identified to collect geometrical and structural data of buildings (second step). In particular, two different forms are designed: one for citizens and a more detailed one for practitioners. The survey forms can be compiled on WebGIS, at the tabs *Building form – Practitioners* and *Building form – Citizens*, or through two mobile apps. The latter were specifically created for the Android operating system version 4.0 or higher and allow to upload data also when internet is not available. All survey data are then uploaded and managed on a WebGIS platform that is the main deliverable of SASPARM 2.0 project [1].

The WebGIS platform collects all compiled forms and, once selected a building, allows to check the corresponding form with all the data, thanks to which vulnerability curves can be calculated (third step). Fragility curves are defined with SP-BELA (Simplified Pushover-Based Earthquake Loss Assessment) method, that is an analytical procedure initially implemented to assess the seismic vulnerability of Italian buildings [3, 4]. In the specific case of Palestine, SP-BELA has been modified to best perform the building environment of those territories, herein represented by the case study of Nablus city.

The last step of the methodology to estimate the seismic vulnerability of Palestinian buildings regards the definition of a criteria that connects each form to a set of fragility curves. The identified criteria allows the association of each set of fragility curves to a building in relation to its structural type and its number of floors.

Once defined the structural vulnerability, seismic risk is calculated by combining the vulnerability to the hazard and the exposure. The WebGIS platform herein presented allows to calculate the seismic risk as defined above and proposes also different retrofit measures for the reduction of it [5, 6].

2   Data Collection

The final result of SASPARM 2.0 project [1] is a WebGIS platform that collects the structural data of the buildings in the city of Nablus. The platform is available to all users, i.e. citizens, students, practitioners, and governmental/non-governmental institutions, and allows the management of data for the definition of vulnerability and seismic risk of each selected building.

Structural data can be collected by compiling two forms, one for citizens and one for practitioners, different from each other only in terms of detail. The compilation of the forms can occur directly on the WebGIS platform or through two apps for smartphones and tablets with Android operating system.

Some information of the forms are mandatory. After clicking on the button *Save* to save the compiled form, the system will check whether the compiler missed some obligatory data. In particular, the message "*Form has some errors or missing fields*" will appear and lacking fields will be notified in red color. To further reduce the number of mistakes, others checks are performed. For instance, if geographical coordinates are wrong (e.g., coordinates results outside the city of Nablus) or the year of construction is bigger than the renovation one, the WebGIS will notify them and will not allow the compiler to proceed until everything will be corrected.

Once filled in properly, all forms are available in the WebGIS homepage at the tab *Map*. The marker corresponding to each form can have two different colors, green or blue, depending on whether the survey has been carried out by practitioners or by citizens. The WebGIS homepage is shown in Fig. 1.
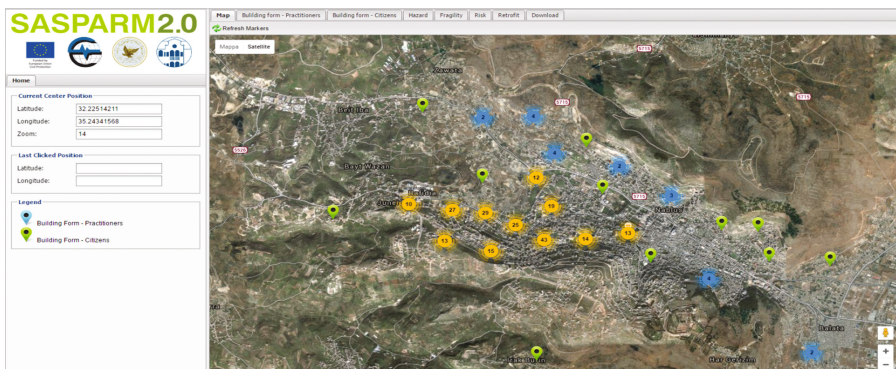
Fig. 1. Tab *Map* - Screenshot of the initial view of the WebGIS to select surveyed buildings. (Color figure online)

By clicking on the marker of the building, in relation to the compiler, the tab *Building form - Practitioners* or *Building form - Citizens* will be activated and all buildings data can be examined.

The buildings detected with the forms described herein are considered as structural units of ordinary construction type (such as masonry, reinforced concrete frame or walls) used for housing and/or services. Therefore, these forms are not suitable for monumental or specialized types (such as industrial depots, sport constructions, theaters, churches etc.).

2.1   Building Form – Citizens

The tab *Building form - Citizens* reflects the survey paper form used by citizens, downloadable in *pdf* format by pressing the button *Help*.

By clicking the button *New Form*, an empty form generates in the WebGIS platform. Once opened, the page can be deleted or closed by using respectively the buttons *Delete Form* and *Close Form*.

At the beginning, the form presents a section dedicated to the compiler information, such as name and level of education (*Education level/Faculty/Department*), as shown in Fig. 2. In this section the compilation date of the form, the name of the compiler and the educational level are mandatory.
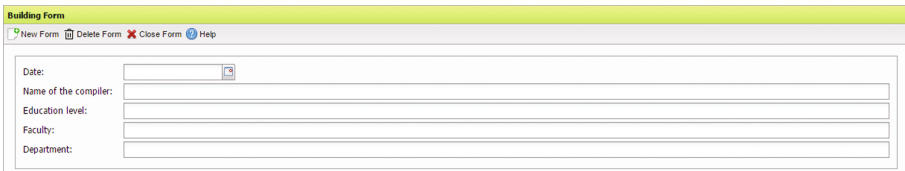
Fig. 2. Initial part of *Building form-Citizens*.

Then, five sections follow, namely respectively *Identification of the Building*, *Description of the Building*, *Structural Data*, *Notes,* and *Photos*, in which the compiler defines the geometric and structural characteristics of the building. Each section contributes to collect the right information to make a quick assessment of seismic performance of the building.

In the section *Identification of the Building*, the citizen enters the data to locate the building, including the geographic coordinates expressed in decimal degrees according
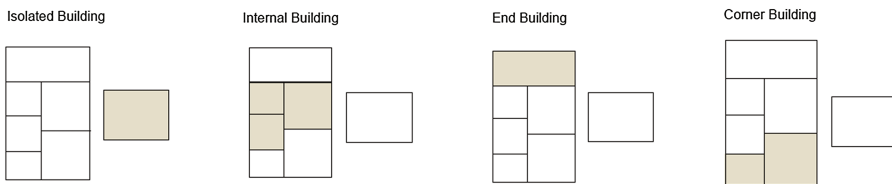

Fig. 3. Description of the different type of building locations.

to WGS84 (World Geodetic System 1984) and detected at the entrance of the structure. Both municipality and geographical coordinates are important to georeference the building so that these data are obligatory.

Since closely related to the seismic response of the building, the definition of the building location is also necessary: in particular, the compiler has to specify if the building is an isolated, inner, end, or corner structure, as indicated in Fig. 3. Figure 4 shows the section *Identification of the Building*.

Fig. 4. Section 1 – *Identification of the Building*.

The section *Description of the Building* contains all the information about the number of floors, the age, the type of use and exposure, and property. The total number of floors of a building has to be marked in *N° Total of floors with the basement*, counting from the foundation, including basements and attic floor, only if accessible. The basements, whose number is marked in *N° Basement*, are all that floors whose height above ground (i.e. the average height above ground in the case of buildings located on a slope) is less than 1/2 of the total height of the floor.

To have an idea about the methods of construction and seismic behavior of the building, the compiler has to indicate the year of construction of the detected building. He can make only two different choices: one is for the period in which the building has been built and the other one is for the possible age in which the building might have had a significant restructuring from a structural point of view. The reference time period for the year of construction is divided into intervals and ranges from <1919 to ≥ 2002.

Regarding the use, it will concern all types of use that may coexist in the building with the related number of units. Finally, the compiler has to specify the percentage of use, the type of property (i.e. public or private) and the number of people that occupy the building. The latter, together with the number of floors and basements are mandatory data.

The section *Description of the Building* is shown Fig. 5.

In addition to the number of floors and the use of the building, to calculate the vulnerability it is important to specify the type of structure.

In *Structural Data* (see Fig. 6), in fact, the compiler has to choose between masonry and reinforced concrete, being the two materials mainly used for the realization of vertical structures of Palestinian buildings.

If the buildings are in reinforced concrete, the total or partial absence of cladding has to be specified, together with the corresponding floors. The absence of cladding, in

Fig. 5. Section 2 – *Description of the Building.*

Fig. 6. Section 3 – *Structural Data.*

fact, favors the occurrence of soft story mechanism in case of medium or high-intensity ground shaking, thus increasing the vulnerability of the building. Since citizens could not identify the vertical structure of the surveyed building, they can avoid to insert this information. In this case, the fragility curves (see Sect. 3.2) are associated to the building only through the number of floors. In particular, if the building has until 4 storeys, it is considered a masonry building otherwise a reinforced concrete one.

Fig. 7. Sections 4 and 5 – *Notes* and *Photos.*

The tab *Building form – Citizen* ends with *Notes* and *Photos* (see Fig. 7) where the compiler can write notes and/or information that cannot be caught in the sections of the form as well as attach photos of the reference building. As shown in Fig. 7, photos can be uploaded or deleted by clicking on *Upload Photo* and *Delete Photo*.

2.2   Building Form – Practitioners

The tab *Building form – Practitioners* in the WebGIS platform is filled in by practitioners. This form is more detailed than the one for citizens. The first difference is in the section *Description of the building* where, in addition to the information required to citizens described above, the compiler has to input the height and floor area, both obtained as the average of heights and surfaces of all detected floors of the building. Figure 8 shows the structure of the section *Description of the Building*.

Fig. 8. Section 2 – *Description of the Building*.

Besides the types of vertical structure already proposed in the tab *Building form - Citizens*, the section *Structural Data* includes also reinforced concrete shear wall buildings. This further classification is relevant because reinforced concrete shear wall buildings have a seismic behavior and a level of vulnerability different from reinforced concrete frame buildings ones. Unlike citizens, practitioners have to indicate if the surveyed building has a masonry vertical structure or a reinforce concrete one.

The section *Structural Data* contains also the part *Horizontal Structure and Roof* where there is a list of horizontal structures, for both interfloor and roof slab, mainly used in Palestinian residential buildings (see Fig. 9). *Horizontal Structure and Roof* provides the possible presence of cantilever structures (e.g., balconies): the latter, in fact, are an important cause to the increase of the detected buildings vulnerability especially for the very common practice to have cladding walls all around cantilever structures. Both horizontal structure and the roof type are mandatory data. Since the type of slab could be a difficult data to gather, the option *Non identified* is automatically selected.

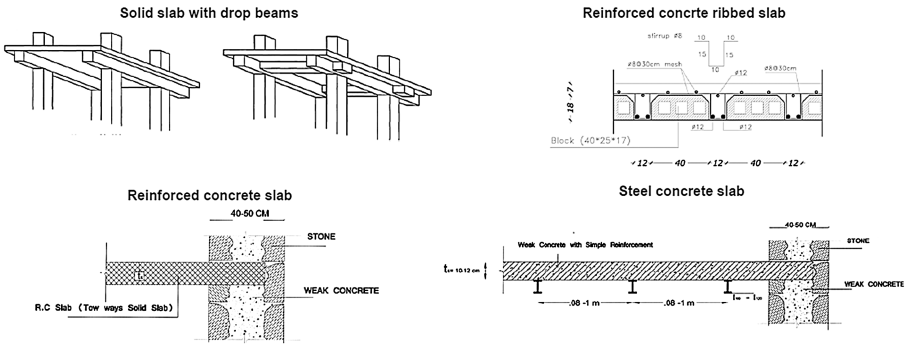Figure 10 displays the structure of the section *Structural Data*.

Fig. 9. Types of slabs mainly used in Palestinian residential buildings.

Fig. 10. Section 3 – *Structural Data.*

Practitioners have to compile also other two obligatory sections, i.e. *Regularity* and *Geomorphological Data*. The latter regard respectively the regularity of the building (both in plan and in elevation), the morphology of the site and the category of the soil foundation on which the building was constructed. The criteria for the definition of the structural regularity and the type of soil foundation are described in Eurocode 8 [7]. Figure 11 shows sections *Regularity* and *Geomorphological Data*.

As for the form of citizens, also the one targeted to practitioners ends with the sections *Notes* and *Photos* to give more detailed information on the detected building.

Fig. 11. Sections 4 and 5 – *Regularity* and *Geomorphological Data.*

2.3 Apps for Compiling the e-Forms Through Smart Phones and Tablets

To make more efficient and faster the collection of survey data, two apps for compiling the e-forms through smartphones and tablets have been developed. These apps run for Android operating system version 4.0 or higher. The apps become useful in case of internet absence: all forms, in fact, can be loaded directly on the smartphone or tablet for offline use. The compiled data will be sent to the web portal once internet becomes available again.

Figure 12 shows the home page of the apps for: (a) citizens and (b) practitioners. The user has to compile all the sections of the form as the ones reported in Fig. 13 for practitioners. The user can save, upload or delete the form at any time only by clicking the button in the upper right, as shown in Fig. 14. In the same list shown in Fig. 14, the button *Send* can be selected once completed the form.
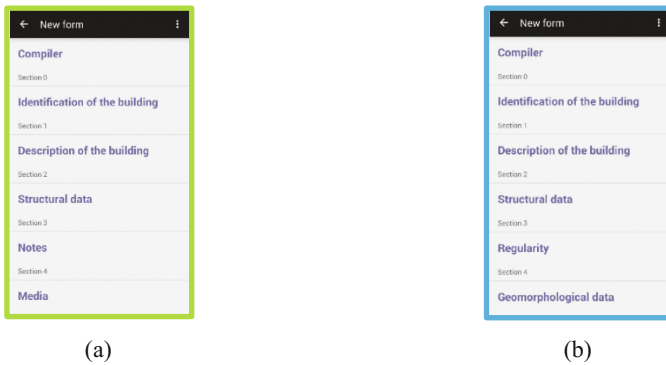

(a) (b)

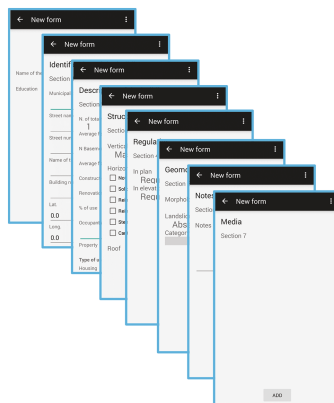**Fig. 12.** Home Page of the SASPARM 2.0 apps for: (a) citizens and (b) practitioners.

Fig. 13. Sections to insert data in the SASPARM 2.0 app for practitioners.
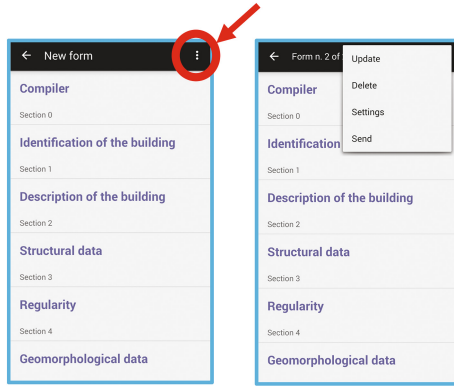
Fig. 14. Operations on the app.

After having sent the form, in relation to the compiler, the form will be available on the WebGIS Platform at the tab *Building form – Citizens* or *Building form – Practitioners.*

3   Estimation of Seismic Risk

3.1   Hazard

The hazard is a parameter that depends exclusively on seismicity of the area. Precisely, the hazard represents the estimation of the expected level of seismic intensity in a certain area and for a given observation period.

The definition of seismic hazard occurs through the hazard curve. In particular, the curve relates the severity of shaking, in this case defined by the peak ground acceleration *PGA*, with the annual frequency of exceedance *AFE*, given by the inverse of the return period T_r.

The logarithm of a ground-motion parameter and the logarithm of the corresponding annual frequency of exceedance can be assumed to be linearly-related, at least for return periods of engineering interest. The negative gradient of the log–log hazard curve is referred to as *k* in this paper, following the definition in Part 1 of Eurocode 8 [7].

Thanks to the approximation of linear trend, to define the hazard curve it is sufficient to determine the *PGA* value, corresponding to a return period T_r, and the negative gradient of the log–log hazard curve *k* that passes through the reference point. Conventionally, the latter is assumed as a point of passage of the curve that corresponds to the return period T_r of 475 years.

The hazard curve is then defined by the relation (1):

$$AFE = AFE_{475} \left(\frac{S \cdot PGA_{475}}{PGA} \right)^k \tag{1}$$

where AFE_{475} e PGA_{475} are the annual frequency of exceedance and the peak ground acceleration corresponding to the return period T_r of 475 years while S is the soil factor. Once defined the hazard curve, it is possible to calculate the seismic demand related to PGA for any return period T_r.

For the case study of Nablus, we considered the "West Bank and Gaza Strip: Seismic Hazard Distribution Map" shown in Fig. 15 that displays the PGA corresponding to a return period T_r of 475 years. Since the gradient k of hazard curve is unknown, the value of k is assumed equal to 3 as suggested in the Eurocode 8 [7].
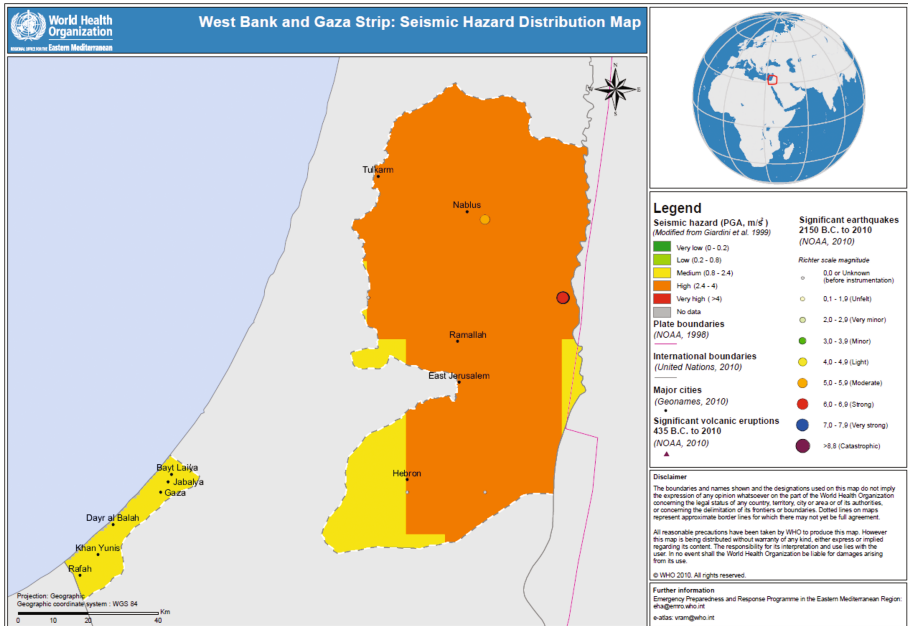
Fig. 15. Hazard Map (West Bank and Gaza Strip).

In summary, the parameters that allow to calculate the hazard curve in the Eq. (1) are:

- AFE_{475} = 1/475;
- PGA_{475} = 0.24 g;
- k = 3;
- S = 1 (soil A), 1.2 (soil B or C), 1.4 (soil D or E) from Eurocode 8 [7].

Figure 16 shows tab *Hazard* corresponding to the selected building and it displays the hazard curve for a soil "C". Since the type of the soil can be specified only in the form filled in by practitioners, the hazard curve related to the forms compiled by citizens is determined by considering the soil type "B".

Fig. 16. Tab *Hazard* – Hazard curve for soil "C".

3.2 Fragility

The structural vulnerability of buildings is evaluated through the definition of fragility curves obtained with the analytical method SP-BELA (Simplified Pushover-Based Earthquake Loss Assessment). In particular, the compilation of the forms allows to collect all the information useful to associate each building to the corresponding fragility curves. Such association is performed in relation to the structural type and the number of floors of each building.

In SP-BELA, fragility curves are obtained by comparing the displacement capacity of representative building classes with the displacement demand for the considered damage levels [8, 9].

In the specific case of the Palestinian structures, only a soft storey mechanism is assumed [10], since most of the buildings have not been designed according to a seismic regulation, introduced in Palestine only nowadays.

According to EMS-98 (European Macroseismic Scale) scale [11], fragility curves are defined for five damage levels: *D1* (slight damage), *D2* (moderate damage), *D3* (extensive damage), *D4* (complete damage), and *D5* (collapse). The relationship between damage levels and limit states numerically identifiable has been defined on the basis of observed damage data in recent Italian earthquakes from Friuli 1976 to Emilia 2012, since specific data for Palestine are not available.

Given a peak ground acceleration *PGA* value equal to 0.24 g (assumed equivalent to a return period T_r of 475 years), Table 1 shows the probability of exceeding of each damage level for 7-storeys reinforced concrete frame buildings and for 3-storeys masonry ones. The corresponding fragility curves, instead, are respectively displayed in Figs. 17 and 18 where the tab *Fragility* of the WebGIS platform is illustrated.

Table 1. Probability of exceeding each damage level calculated by applying SP-BELA and HAZUS [12] for a PGA = 0.24 g (T_r = 475 years).

	DL1	DL2	DL3	DL4	DL5
7-storeys concrete frame buildings	98.30	77.61	71.12	55.36	14.85
3-storeys masonry buildings	100	99.9	99.8	97.5	55.7
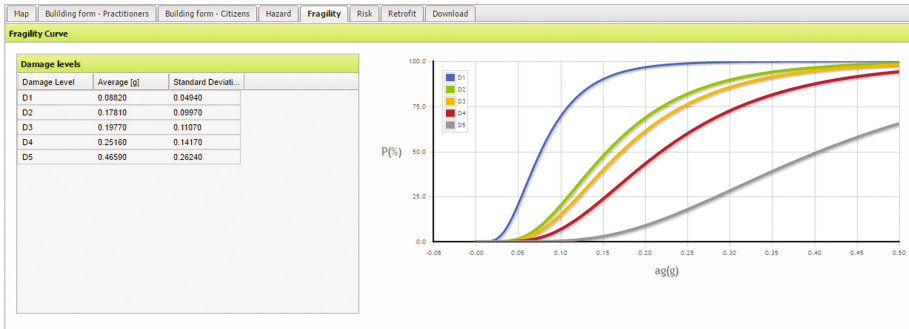
Fig. 17. Tab *Fragility* – Fragility curves for 7-storeys reinforced concrete frame buildings.
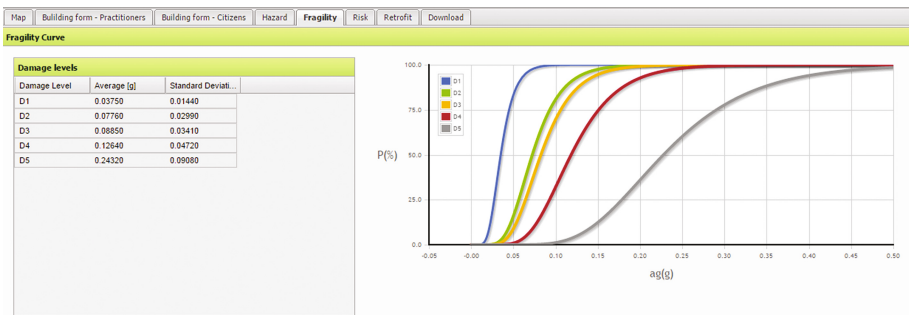
Fig. 18. Tab *Fragility* – Fragility curves for 3-storeys masonry buildings.

The definition of fragility curves for reinforced concrete shear wall buildings has not been tackled trough mechanical methodology since it is not possible to identify a prototype building which can be representative of the whole building stock. As a matter of fact, the shear wall layout does not have a standard which could be assumed as representative.

To face this problem, fragility curves of reinforced concrete shear wall buildings have been obtained from the fragility curves of reinforced concrete frame buildings with the same number of storeys. The assumption herein considered is that the presence of shear walls reduces the average value of the fragility curves calculated for reinforced concrete frame buildings whereas the coefficient of variation remains constant.

To calibrate the correction factor that allows to determine the fragility curves of reinforced concrete shear wall buildings, a careful bibliographic study has been undertaken. Specifically, the vulnerability study presented in HAZUS [12] has been selected: HAZUS manual, in fact, proposes fragility curves for different structural types. By comparing HAZUS fragility curves of frame buildings with masonry infill walls with HAZUS fragility curves of shear wall buildings, a correction factor equal to 1.3 has been defined.

Figure 19 shows the fragility curves calculated for 10-storeys reinforced concrete shear wall buildings located in Nablus.

Fig. 19. Tab *Fragility* - Fragility curves for 10-storeys reinforced concrete shear wall buildings.

3.3   Risk

The combination of vulnerability, exposure and hazard allows to calculate the seismic risk.

Precisely, once selected a building, the seismic risk related to it is reported at the tab *Risk* which contains the probability to reach the five levels of damage from *D1* to *D5* of EMS98 scale [11] in three observation time frames T_d of 1, 10 and 50 years.

Figure 20 shows the risk values related to a selected 8-storeys reinforced concrete frame building, not regular both in plan and in elevation and recently built.
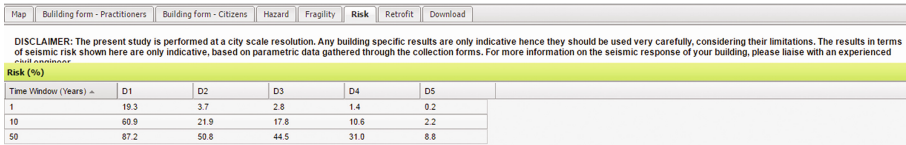

Fig. 20. Tab *Risk* - Risk values related to a selected 8-storeys reinforced concrete frame building, not regular both in plan and in elevation and recently built.

To reduce the seismic vulnerability and consequently the risk, different structural interventions are suggested in the tab *Retrofit* of the WebGIS [5, 6]. As shown in Fig. 21, the tab *Retrofit* is organized according to the different types of buildings defects, mainly due to a non-seismic design. Structural defects induce the building to have a non-ductile behavior and to be more predisposed to the damage, even in case of low or medium intensity ground shaking. As a consequence, the proposed rehabilita- tion measures vary from case to case and depend on the type of building as well as on
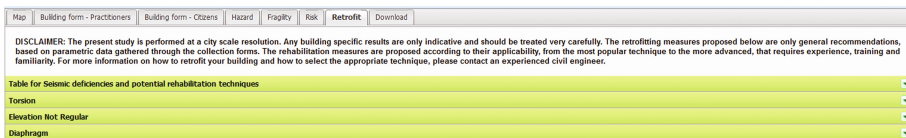

Fig. 21. Tab *Retrofit.*

its geometrical and structural characteristics that can be identified through the completion of the forms.

4   Conclusion

This paper describes the WebGIS realized for SASPARM 2.0 project [1]. It is structured in a very simple and intuitive way and allows free access to all users, i.e. citizens, practitioners, students, and governmental and non-governmental institutions. In particular, each user can upload or consult all information relevant to the definition of the vulnerability and the seismic risk of residential buildings in the city of Nablus.

This information regards the geometrical and the structural data of buildings which are surveyed through the use of two forms, one for citizens and one for practitioners, designed for this purpose. Citizens and practitioners can compile the forms either directly on the WebGIS platform or by using two mobile apps that were specifically created for Android operating system.

By using the survey data and SP-BELA method, in relation to the structural type and the number of floors, fragility curves are defined for five different levels of damage.

The structural vulnerability is then combined to the local seismic hazard, thus obtaining the seismic risk for three observation time windows.

Finally, possible retrofit measures are also suggested to reduce the seismic risk of each selected building.

Although it started as an instrument to be used on the Palestinian territory, the WebGIS of SASPARM 2.0 is a very useful tool that could be used also in others countries, such as Italy, to collect all vulnerability data of residential buildings that are still not available on a national scale.

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