SESGAL Software for Managing Earthquake Risk in Galicia

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Abstract: According to the laws in place in Spain, the autonomous Community of Galicia (NW Spain) has two zones –Lugo and Ourense– at greater seismic risk. In order to control and minimize the damage to buildings and to population, a Special Civil Protection Plan for Seismic Risk in Galicia (SISMIGAL) has been drawn up, including a software tool specially designed for this purpose.

The Galician Seismic Scenario Simulator v1.0 (SESGAL) is based on a geographic information system (GIS) and provided with a comprehensive database of the elements and resources that intervene in the management of an emergency. In addition to the typical functions of GIS, SESGAL incorporates a seismic scenario simulator –which enables the prediction of the effects of an earthquake– and a seismic emergency manager –which provides a tool for addressing the needs of the population in case of a catastrophe.

The SESGAL software presented here provides a useful, rapid tool for an effective and efficient response to the damage caused by an earthquake in the Galician territory, managing the means and resources available.

1 INTRODUCTION

A new Spanish Earthquake-Resistant Construction Standard (NCSE-02) was approved by Royal Decree 997/2002, of 27 September, replacing the previous standard in place since 1996. This new regulation was drawn up in accordance with current earthquake engineering and seismology knowledge, including an updated seismic risk map that identified two zones in Galicia – Lugo and Ourense – with different seismic acceleration and so at greater risk.

The Basic Civil Protection Regulation, approved by Royal Decree 407/1992, of 24 April, to complement and develop Law 2/1985, of 21 January, governing civil protection, includes earthquakes among the risks that could result in a catastrophe and so require special planning.

The Galician Territorial Civil Protection Plan (PLATERGA) – within the legal powers assigned to this autonomous region – provides for the need to develop a plan to address earthquake risk in the region. The Special Civil Protection Plan for Seismic Risk in Galicia (SISMIGAL) was thus drawn up to ensure effective and coordinated use of public and private resources and means to minimize the consequences for people, property and the environment of a possible earthquake. The main novelty of this plan is that it includes a specially designed software tool called SESGAL (Galician Seismic Scenario Simulator) v1.0. SISMIGAL and SESGAL, whose territorial scope is the entire geographic area of Galicia, are activated for any seismic movement affecting the region with consequences for the population and property.

Most seismic plans consist of a set of documents (memoranda, reports, schedules and plans); the Galician seismic plan also includes the specially developed computer application SESGAL. SESGAL enables digital databases to be queried and seismic events and their possible consequences to be simulated; it also provides decision-making support during earthquake emergency management.

The SESGAL software reflects all the features of the SISMIGAL, as follows: it characterizes seismic risk in Galicia, taking hazard and vulnerability estimates as a starting point; it catalogues the means and resources available for planned earthquake actions; it describes the organizational and functional structure for emergency interventions in earthquakes; and it establishes precise emergency

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intervention steps aimed at evaluating earthquake consequences, providing assistance to the affected population and minimizing the people-property impact.

Earthquakes and their consequences have been widely studied and modelled, existing a number of tools and software developed in order to model this kind of natural event such as Hazus (FEMA, 2003) or CAPRA (CAPRA, 2012). Hazus is a GIS-based model used for the estimation of potential losses due to natural disasters in the USA, while CAPRA assesses Central American communities by estimating physical, economic and human risks derived from an earthquake. NISEE (NISEE, 2011), a public service project of the Pacific Earthquake Engineering Research (PEER) Center Library, has developed several tools in the field of earthquake engineering which focus on the response of buildings and infrastructures.

Other works can be found in the literature covering the study of mitigation alternatives in order to avoid or minimize losses in future earthquakes (Gupta and Shah, 1998); (Dodo et al., 2007) and facilitate the recovery of damaged environmental structures (Du et al., 2012).

However, the vast majority of the existing models don’t comprise the stage of response to the emergency. The Karmania hazard model (Hassanzadeh et al., 2013) allows the simulation of an earthquake in the region of Iran, as well as the estimation of the resources needed after the seism in terms of emergency facilities, food and water. China has a simulation system based on GIS and Artificial Intelligence (Tang and Wen, 2009) which includes a seismic emergency response module similar to the Seismic emergency manager developed in this work.

Nevertheless, the SESGAL Seismic emergency manager addresses the Spanish and Galician Civil Protection policies and structures, and allows the establishment of several advanced command posts to manage and coordinate the response in this territory.

Time is critical and effective emergency activities are essential in order to minimize the death rates among people trapped in building collapses (Coburn et al., 1992). The main advantage of SESGAL is that it ensures a practical and agile response to emergency situations when rapid decision making is key to minimizing seismic damage.

The application provides information down to the level of the parish, being this detailed, exhaustive database one of its strenghts. SESGAL has three main functions:

(1) Layer Viewer. The software is based on a geographic information system (GIS) and so can query a cartographic database (scale 1:50000) and a number of other elements that intervene directly or indirectly in the management of an emergency. For municipalities at the highest seismic risk in Galicia (As Nogais, Baralla, Becerreá, Láncara, Samos, Sarria and Triacastela) more detailed maps (scale 1:5000) are provided.

(2) Seismic Scenario Simulator. The effects of an earthquake can be simulated and investigated according to the epicentre, depth and magnitude (or intensity).

(3) Seismic Emergency Manager. The damage to buildings and services and the number of people that will need medical care can be assessed. Hospital resources and medical care can also be allocated according to evolution over time of the situation regarding injuries. This allows the coordination of the means and resources available after an earthquake, optimizing the response to a disaster of such nature.

1.1 Geological and Seismic Context

Galicia is located in the Hesperian or Iberian Massif, one of several old Variscan massifs that stretch across the European continent. Tectonic readjustments of this massif are responsible for most of the seismicity experienced in Galicia. Seismic events offshore that could result in tsunamis are also possible.

Table 1: Seismic events of magnitude 4 and higher (Galicia 1995-1997).

Lat.	Long.	Depth	Int.	Mag.	Location
29 November 1995					
42.8167	-7.3033	9 km	VI	4.6	NW Triacastela (Lugo)
24 December 1995					
42.8600	-7.3150	15 km	VI	4.6	SW Baralla (Lugo)
29 October 1996					
42.8300	-7.2283	-	V	4.1	SW Becerreá (Lugo)
21 May 1997					
42.8167	-7.2333	9 km	V	4.1	N Triacastela (Lugo)
42.7833	-7.2583	13 km	VI	5.1	NW Triacastela (Lugo)

Source: National Geographic Institute (Spain).

Seismic events recorded in Galicia since the late 1970s, and especially the series of earthquakes in Sarria-Becerreá (Lugo) in the 1990s, have led to a change in categorization in the national seismic hazard map, so that this is now the area of greatest seismic activity in the northwestern Iberian Peninsula (López-Fernández et al., 2004). Until 1995, seismic activity in this region was unremarkable, but between 1995 and 1997 there were more than 500 earthquakes, four of magnitude 4 and, on 21 May 1997, one of magnitude 5.1 (Table 1).

2 METHODOLOGY

Our seismic risk assessment took into account not just the territory of Galicia, but also nearby terrestrial and marine areas.

Seismic risk is defined by the expected number of people affected, the expected damage to property and the expected disruption to economic activity due to an earthquake. Seismic hazard is defined as the probability, for a given location, of the occurrence of an earthquake of a certain intensity, and its inverse, the return period.

2.1 Database and Organization

The cartographic databases, comprising the graphical representation of the maps, are stored in files with the extension .shp and the associated data are stored in files with the extension .dbf.

The software uses a georeferenced spatial database associated with digital maps in vector format (scale 1:50000 in general and 1:5000 for high risk areas). The thematic maps are composed of layers (with georeferenced information on polygonal areas, lines and points) containing entities of different categories, with each record in the database representing an entity (Figure 1).

A satisfactory response to an emergency depends, above all, on accurate knowledge of the means and resources available. Taken as the database was the Territorial Civil Protection Plan (Xunta de Galicia, 2009), whose information was georeferenced for inclusion in SESGAL.

Means refer to essentially mobile human and material elements that make up the emergency teams. Resources are all the essentially static natural elements or materials that can be used in emergency situations. These catalogued means and resources are classified in four levels: municipal, provincial, regional and state.

SISMIGAL is structured and organized according to general basic civil protection models developed in the national Basic Civil Protection Master Plan for Seismic Risk and the Galician Territorial Civil Protection Plan (PLATERGA). The head of emergency management is also the director of the master plan and is assisted by an advisory committee. Orders are implemented by teams of experts coordinated at the site of the emergency by the manager of an advanced command post.

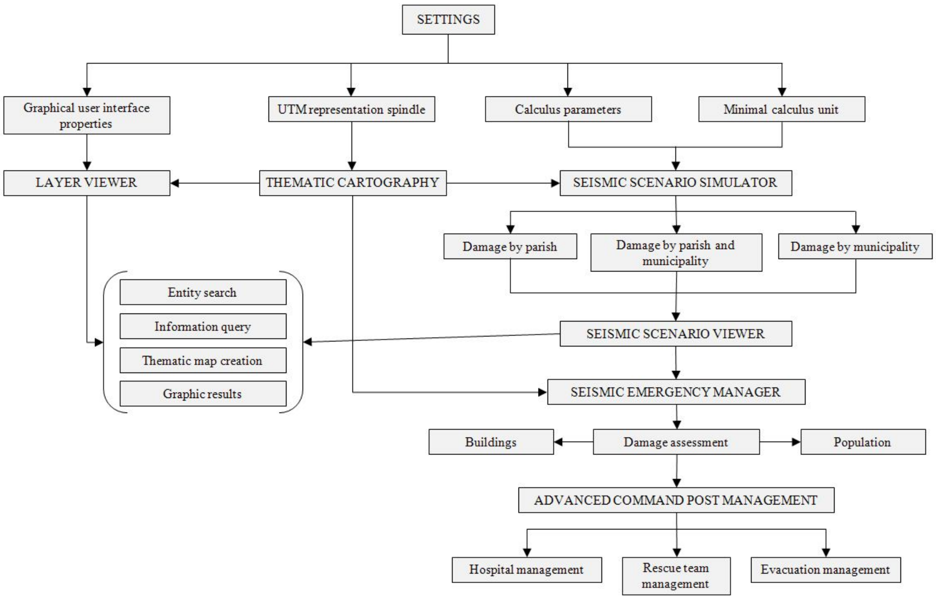


Figure 1: SESGAL information system structure.

These teams are the operational spearhead of the overall plan. Each team has its own operational plans, depending on its mission.

Thus, the direct intervention team acts to minimize and control the effects of the earthquake, the seismic team evaluates and monitors earthquake damage, the technical support and essential services team deals with damage to key services, the health and social action team provides care to victims and the logistics and security team ensures public safety and public order.

2.2 Seismic Scenarios

First characterized are different possible seismic scenarios for Galicia, considering different magnitudes and intensities and propagation models, and estimating the effects on people and property. The identification of areas of Galicia where seismic emergencies might occur is based on: (1) assessment of seismic hazard, estimated from the intensity of the movement that can reasonably be expected in any given parish; and (2) assessment of the vulnerability of buildings so as to establish an estimate of the damage that could be generated by an earthquake.

Taking the basic acceleration value for each municipality and the expression that relates this to intensity (Eq. 1), we obtain a map of seismic intensities by municipality:

$$\log_{10} a = 0.30103 * I - 0.2321 \quad (1)$$

where a is expressed in Gals ($10^{-2} m/s^2$).

2.3 Seismic Vulnerability

The vulnerability of people (injuries and fatalities) and buildings (homes, essential services and lifelines) are determined and potential damage from a hypothetical earthquake is assessed.

2.3.1 Seismic Vulnerability of Buildings

The vulnerability of buildings depends on many factors, among which are the characteristics of the soil, the kind of foundation, the building geometry and age, to name just the main factors (Maldonado et al., 2007); (Maldonado and Chio, 2009).

The European Macroseismic Scale (EMS-98) (Grunthal, 1998) assigns a vulnerability class to each structure depending on its construction characteristics and the classification of damage to masonry and reinforced concrete buildings. Six vulnerability classes (A to F) are defined, with A as the most vulnerable and F as the least vulnerable.

Following the guidelines of the EMS-98, Galician houses were assigned to vulnerability classes based on characteristics provided in the National Institute of Statistics' Population and Housing Census for 2001. Two different approaches were followed, resulting in two classifications:

(1) Classification by age, as per the SES2002 simulator (Barranco and Izquierdo, 2002).
(2) Classification by age and height, following the vulnerability assessment of essential buildings made for Catalonia (Gonzalez et al., 2001).

Furthermore, two matrices are used to estimate the damage of buildings according to the seismic intensity of the area assigned by the European Macroseismic Scale (EMS-98):

(1) Type 1 matrix: considers the average percentage of the intervals defined by EMS-98 (8% = "very few", 35% = "many" and 80% = "most").
(2) Minimum vulnerability matrix: considers the lowest percentage of each EMS-98 interval (1% ="very few", 15%="many" and 55%="most").

2.3.2 Seismic Vulnerability of the Population

To estimate the number of fatalities and injuries and also the number of people left homeless by the earthquake, a series of matrices are used that take building vulnerability as the starting information.

We use three methods to estimate the number of people potentially affected by an earthquake, one based on an estimate of the number of collapsed houses (Coburn et al., 1992), and an Applied Technology Council (ATC) method called ATC-13 (1985), based on the degree of damage to the buildings. The first method is applied in two ways: with a temporary factor which considers the influence of the time of the day and seasonal occupancy (i.e. weekdays vs. weekend), and without this temporary factor.

Applying Coburn et al. (1992) formulae to Galicia, the number of deaths is calculated by:

$$K = 0.3 * G5 * Om \quad (2)$$

where G5 is the number of collapsed buildings and Om is number of people per building (1.91 in rural areas with less than 10,000 inhabitants, and 2.31 in urban areas).

The number of injured people is assumed as six times the number of killed people. Finally, the number of people left homeless is estimated as follows:

$$H = CI * Om \quad (3)$$

where CI is the number of uninhabitable houses (all those buildings which suffered damages of G5 or G4 level, plus half of the buildings with G3 level damage).

On the other hand, ATC-13 method estimates the number of people slightly injured, seriously injured and killed depending on the damage suffered by the buildings, from G1 to G5.

A census of the population and buildings is also made using demographic data from the 2001 census for all the municipalities in Galicia.

2.3.3 Seismic Vulnerability of Key Buildings

A key building is any building housing a service whose malfunction may preclude or hinder measures to deal with a seismic crisis and return operations to normal.

The vulnerability of essential buildings is calculated based on the year of construction and height (as with residential buildings). In cases where this information is not available, the ATC-13 (1985) methodology is used.

2.3.4 Seismic Vulnerability of Lifelines

Damage to the road and rail networks, to natural gas supplies and the electricity grid, etc is studied and assessed using the ATC-13 (1985) and ATC-25 (1991) methodologies. The damage is classified in the same way as for key buildings.

2.4 Damage Estimation

Taking into account the vulnerabilities above mentioned, it is also estimated the damage to buildings and the population through the theorem of total probability (Benjamin and Cornell, 1970). Each type of building is a combination of different vulnerabilities, so the probability of suffering a damage of *d* degree is calculated as follows:

$$P\,[GD = d] = \Sigma\, P\,[GD = d|V,I]*P[V]*P[I] \qquad (4)$$

where P[GD= d|T,I] is the probability of a damage of *d* degree given an intensity *I* and a vulnerability *V*; P[V] is the probability of the building having a vulnerability *V*; P[I] is the probability of the occurrence of an earthquake of intensity *I*. Considering the intensity in a deterministic approach, being P[I]=1, the cumulative probability of suffering a damage *D* is calculated as follows:

$$P\,[GD=D\geq d_j] = 1-\Sigma\, P[GD = d_i], \quad \text{with } i = 0,\ldots, j-1;\ j=1,...,5 \qquad (5)$$

Damage to buildings is classified in five classes (G1=slight, G2=moderate, G3=severe, G4=destruction, G5=collapse), while victims are classified as homeless, injured or dead.

2.5 Earthquake Simulation Process

Once the coordinates for a simulated earthquake are entered in the program, the isoseismal radii and the intersections are calculated for municipalities, parishes or both simultaneously. It is assumed that the logarithm of the parameter of movement in a certain location follows a normal distribution. Hence, the attenuation of the intensity is calculated in the epicentre surroundings down to intensity 3 at the edge.

3 THE SESGAL APPLICATION

3.1 System Requirements

The SESGAL application was programmed using Visual Basic to operate in Windows XP operating system. The mid-level hardware requirements are 1 GB of free hard-disk space and 512 MB of RAM.

3.2 Settings

Through the settings/properties menu, the user can select the program environment settings, results presentation settings and the calculation parameters. Within this last option the user can select the vulnerability matrices to be used in the simulation, both for the population and buildings.

3.3 SESGAL Functions

As already indicated, the functions offered by the SESGAL application are the layer viewer, the seismic scenario simulator and the seismic emergency manager. The latter two are the elements that distinguish this application.

3.3.1 Layer Viewer

This module is responsible for the tasks typical of a GIS. It allows access to all the maps and associated databases, while allowing the user to perform the more general tasks of a vector GIS. Access is via the file/layer viewer menu.

Displayed directly on the screen are data on Galicia down to the parish level, including information on the vulnerability of buildings calculated by the two methods described above. It is thus possible to know, for any given zone, the number of buildings with a specific level of vulnerability (A to F). Furthermore, the seismic intensities calculated from Eq. (1) and the geology of the region (soft, medium or hard bedrock) can be consulted. Figure 2 shows the resultant map, which uses increasingly dark colours to indicate areas of greater risk.

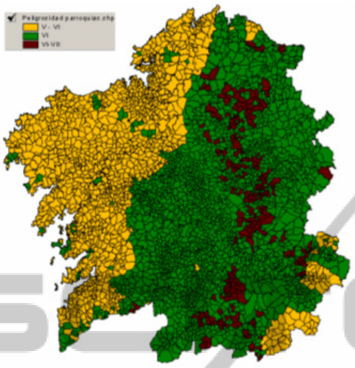


Figure 2: Map of seismic intensities by parish.

The layers consist of the following information groups: basic maps, resources and means, essential services and lifelines and detailed maps (including street maps of towns belonging to the seven municipalities most vulnerable to seismic damage).

3.3.2 Seismic Scenario Simulator

Using the file/simulate earthquake menu and entering earthquake parameters in the program, the user can obtain estimates of expected seismic intensities and the impact on people and buildings. Earthquakes and their effects can be simulated by introducing the location of the epicentre (by its coordinates or clicking on the map directly), the depth and the magnitude (or intensity) of the earthquake at the epicentre (Figure 3).

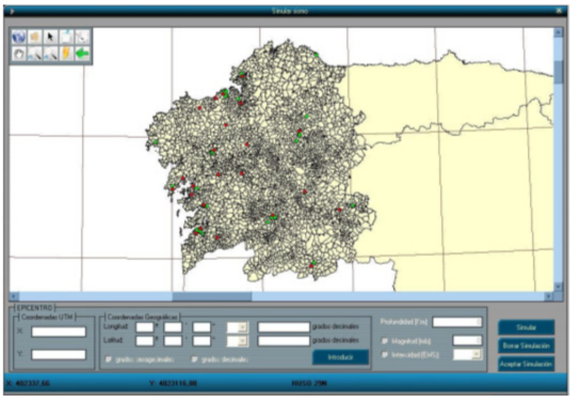


Figure 3: Earthquake simulation window.

It is also possible to simulate a past earthquake whose parameters are stored in the program database.

The results screen (Figure 4) shows the epicentre and the intensity of the earthquake at the epicentre, the intensity in nearby municipalities, the list of municipalities affected and the hospitals and fire stations available.

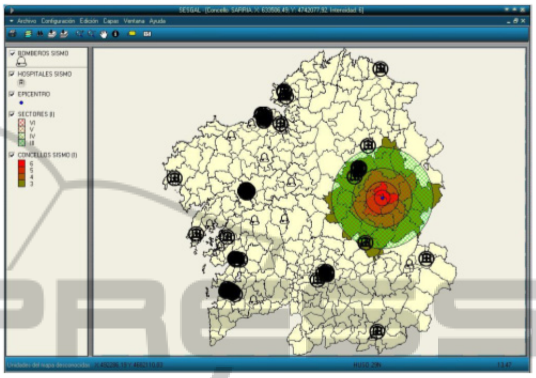


Figure 4: Results of an earthquake simulation.

This module allows results for a total of five earthquakes to be simulated and viewed independently and simultaneously.

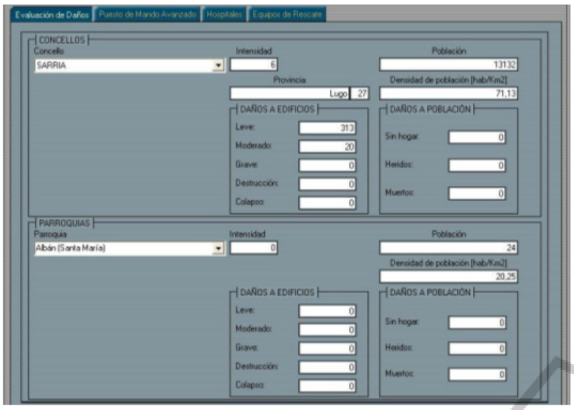
3.3.3 Seismic Emergency Manager

The results of the seismic simulation(s) can be used to manage the means and resources that participate directly in the emergency. From the results window for the earthquake, the file/management main menu option launches the emergency management module.

The management window (Figure 5) contains the following tabs: damage assessment, advanced command posts, hospitals and rescue teams. The damage assessment tab shows damage to buildings, damage to the population classified by municipalities and parishes and intensity information for the earthquake in that area.

Using the displayed forms, real-time information for locating and managing an emergency from the advanced command post can be entered in the database.

The first step in emergency coordination is location of the advanced command post by entering UTM coordinates or by directly indicating its position on the map. More than one advanced command post can be established to manage earthquake victims in the corresponding area. Each advanced command post is identified by a unique code automatically generates once a location is chosen.



Concello: SARRIA
Intensidad: 6
Población: 13132
Provincia: Lugo 27
Densidad de población [hab/Km2]: 71,13
Leve: 313
Moderado: 20
Grave: 0
Destrucción: 0
Colapso: 0
Sin hogar: 0
Heridos: 0
Muertos: 0

Parroquia: Albán (Santa María)
Intensidad: 0
Población: 24
Densidad de población [hab/Km2]: 20,25
Leve: 0
Moderado: 0
Grave: 0
Destrucción: 0
Colapso: 0
Sin hogar: 0
Heridos: 0
Muertos: 0

Figure 5: Management window showing the damage assessment tab.

The triage tool manages medical care for earthquake victims and assesses damage to hospitals. The first triage indicates the number of injuries and fatalities. A damaged hospital triage classifies hospitals according to their state after the earthquake. If hospitals in the affected area are damaged, the initial triage would also include the patients in this hospital.

In a second triage, victims are classified as dead or injured, for three injury severity levels (minor, serious and very serious). This second triage enables victims to be assigned to hospitals according to the care and equipment required and proximity to the advanced command post.

Depending on needs, enquiries can be made to hospitals about bed numbers, operating theatres or any other useful information. Hospitals can be searched for by two criteria: isochrones or roads. The former locates hospitals at a distance of 20 minutes, 1 hour or 3 hours from the advanced command post, whereas the latter evaluates the shortest route in terms of time required to cover the distance from the advanced command post.

Once all the search criteria have been established, the program queries the thematic database and calls up a list of hospitals that match the criteria, starting with the nearest in time. Once suitable hospitals have been located, victims are assigned to them.

Once the earthquake victims are quantified and classified and hospitals have been selected for them, a medical transport evacuation plan (Figure 6) is organized. The screen displays all the available medical transport, classified as standard transport vehicles, basic ambulances, emergency ambulances and air ambulances (helicopters). A query calls up a form providing availability information regarding vehicles in the category consulted.

The hospitals tab presents administrative and technical data information for each hospital and also displays a map of the municipalities and parishes in the hospital's catchment area. The user can also make an assessment of the emergency response capacity of a hospital using two analytical components in SESGAL: the number of referrals generated by the hospital and the hospital response factor. The number of referrals quantifies the number of patients to be evacuated from a hospital in the event of earthquake damage, whereas the hospital response factor evaluates the emergency care provided by the hospital.

AMBULANCIA ASISTENCIAL POBRA DE TRIVES
En base: 3
En tránsito: 1

A FONSAGRADA | 51' 0'': 1
En base: 7
En tránsito: 2

Lugo | 31' 0'': 1
En base: 1
En tránsito: 0

BASE H-4 | 19' 48'': 1
En base: 1
En tránsito: 0

Figure 6: Evacuating earthquake victims to hospitals.

Finally, the rescue team tab refers to the means and resources available for major rescue operations, primarily, fire-fighters and civil protection volunteers. The search and selection procedure for these teams is similar to that used for the hospitals.

4 VALIDATION

In order to validate the performance of the seismic scenario simulator, the historical earthquakes from Table 1 have been simulated.

The results show no casualties or injured people, with a large number of buildings with slight and moderate damage (1769 and 510, respectively), 164 buildings severely damaged and 34 destructed (not collapsed). According to the information gathered in that date, the results of the simulation basically agree with the real consequences of the selected earthquake. However, no seriously damaged buildings were reported at that time, what makes the seismic scenario simulator a conservative tool.

Regarding the seismic emergency manager, it has not been used yet in real situations, but it will prove to be an effective application as long as the databases are updated.

5 CONCLUSIONS

The main objective of the seismic risk plan for Galicia (SISMIGAL) is to limit the impact of possible earthquakes on people, property and the environment.

The SESGAL software for simulating an earthquake scenario rapidly and efficient assesses damage and facilitates the management of available means and resources. Being GIS-based, it incorporates two specially designed modules for seismic risk management: a seismic scenario simulator and a seismic emergency manager. These quickly estimate the damage caused by an earthquake to the population and buildings and coordinate the means and resources available to provide assistance to victims and minimize the impact of the earthquake.

The application was validated through the simulation of historical earthquakes whose consequences have been reported, obtaining coherent results from the seismic scenario simulator.

The effectiveness of SISMIGAL depends largely on the ability to maintain an organization capable of rapidly providing a coordinated response to the chaos resulting from a seismic event.

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