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# A new tool to simulate ground shaking and earthquake losses

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## Abstract

The main purpose of this suite is Planning and Management of Seismic Emergencies before and after future damaging earthquake. This tool is written in ArcGIS software executing a fast and efficient determination of the estimated shakemaps and damage scenarios. The tool allows to select the earthquake source parameters through a defined database; moreover ground motion prediction equations can be chosen and they can be combined according to the study area features. The local site effects are characterized from Vs30 values, which have been achieved by topographic slope as a proxy (even with local correlations) obtained from digital elevation model. The elements exposed to risk are incorporated from the cadastral database after inputs has been refined through an automated analysis. Vulnerability and estimated losses can be determined either empirically (EMS-98 scale and Vulnerability Index, Iv) or analytically (Capacity spectrum). Additionally, a vulnerability modifier is implemented to account soil-structure resonance. Epistemic uncertainties are quantified in the input parameters using a logic tree. This tool has been validated through a representative seismic scenario: the 1910 Adra earthquake (southern Spain) with moment magnitude ($M_w$) 6.3 and macroseismic intensity VIII (EMS-98 scale) proving the reliability of this program.

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## 1. Introduction

Seismic risk management involves the physical and structural consequences of an earthquake and the socio-economic considerations affecting the current population or even future generations. Therefore, it integrates evaluation of the risk and the corresponding adopted decisions in order to improve the seismic resilience.

The Iberian Peninsula shows a low to moderate seismicity in the world context with frequent earthquakes of moment magnitude ($M_w$) generally smaller than 5.5, although, historically, large damaging earthquakes have occurred with epicentral macroseismic intensity ($I_0$) IX-X in the EMS-98 scale [1], as those of 1829 Torrevieja (Alicante) and 1884 Arenas del Rey (Granada). Both earthquakes caused the collapse of many buildings and a high number of human losses [2].

Recently, several instrumental earthquakes occurred in southeast of Spain, such as: Adra (Almería) 1993 and 1994; Mula (Murcia) 1999; Bullas (Murcia) 2002; La Paca (Murcia) 2005 and Lorca (Murcia) 2011, with magnitudes ($M_w$) between 4.7 and 5.2 respectively, and $I_0$ ranging from V to VII (EMS-98 scale [1]). These shocks have shown the relevance of shallow geology for explaining not only the ground motion amplification but the degree and spatial distribution of building destruction [3,4,5,6,7,8].

Consequently, preventive decision-making aimed at doing recommendations for the mitigation of seismic risk is more effective if seismic emergency managers (Civil Protection) have user-friendly software capable of estimating damage and loss scenarios in future earthquakes. This information is essential to develop Seismic Emergency Plans at local level for the municipalities because they establish the organization scheme and action procedures needed to effectively deal with the earthquake emergency. Such procedures are of great importance for any seismically active region, regardless of the level of seismic hazard. The tool has been created based on these ideas.

One of the first seismic risk suites in Spain having this goal in mind is “Simulador de Escenarios Sísmicos-SES2002” [9]. This software was created specifically for the Civil Protection and although it has been widely used, nowadays it is not up to date.

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After the development of HAZUS [10], known as a reference for the earthquake losses estimations, numerous modelling tools have been developed by scientists worldwide to estimate seismic risk, although mainly focused on the scientific community. Table 1 shows a summary of these tools with a brief comparison in terms of methodologies and results.

**Table 1**. Summary of some of the main earthquake loss estimation (ELE) tools currently published and the comparison with SISMOTOOL

| Tools Description | HAZUS® [10] | SES 2002 [9] | SEISMOCARE [11] | SELENA [12] | CAPRA [13] | Armagedom [14] | OPENQUAKE [15] | SISMOTOOL |
|---|---|---|---|---|---|---|---|---|
| GIS integration | ESRI ArcGis | Map Objects (own GIS) | MapInfo | No | Own GIS | Own GIS | QGIS | ESRI ArcGis |
| Open Source | No | No | No | Yes | No | No | Yes | Yes |
| Seismic scenario | Deterministic Pre-computed shake Map Probabilistic | Deterministic | Deterministic | Deterministic Probabilistic | Probabilistic | Deterministic Probabilistic | Deterministic Probabilistic | Deterministic Pre-computed shake Map |
| Ground motion parameter | Spectral acceleration | Macroseismic intensity | PGA | Spectral acceleration | PGA | Macroseismic intensity<br>Spectral acceleration | Spectral acceleration | Spectral acceleration |
| Site effects: Vs30 values and topography factors | Yes (soil amplification factor or amplified shakemaps) given by users | No | Yes (soil amplification factors) given by users | Yes (soil amplification factor; amplified shakemaps and topographic amplification factors) given by users | Yes (computation of amplified shakemaps using transfer functions) given by users | Yes (soil raster file, Liquefaction susceptibility raster file, landslide susceptibility raster file) given by users | Yes (soil amplification factors) given by users | Yes (soil amplification factor; amplified shakemaps and topographic amplification factors) given by users or computed by the tool |
| Exposure | Buildings Infrastructures Population | Buildings Population | Buildings Infrastructures Population | Buildings Population | Buildings Population | Buildings Population | Buildings Infrastructures Population | Buildings Population |
| Interface to generate vulnerable elements | No | No | No | No | No | Yes | No | Yes |
| Vulnerability estimate | USA buildings typologies | No | No | No | No | Yes | No | World-wide buildings typologies |
| Resonance Soil-Structure | No | No | No | No | No | No | No | Yes (empirical) |
| Damage computation | Analytical | Empirical | Empirical | Analytical | Analytical | Empirical Analytical | Analytical | Empirical Analytical |
| Results Viewer | Buildings, lifelines and essential facilities damage. Fire-following earthquake and Debris generation. Economic losses, Casualties and Shelter. Indirect Losses | Seismic intensity. Building damage. Casualties | Building damage. Casualties. Cost of damage | Shakemaps in terms of spectral acceleration. Building damage. Casualties. Cost of damage. Estimation of debris and shelter requirements | Physical exposure of construction. Direct economic losses. Probabilistic Risk: Average annual loss and Probable maximum loss. | Shakemaps in terms of intensity and spectral acceleration. Building damage. Casualties | Loss of life. Property damage and social and economic disruption due to earthquakes | Shakemaps in terms of intensity and spectral acceleration. Building and dwelling Damages. Economic losses. Casualties and Shelter |

Therefore, the aim of this paper is to show a new tool (SISMOTOOL) integrating strengths of the known platforms and incorporating new methodologies to reinforce the Civil Protection system. In particular, SISMOTOOL can automatically: a) compute amplification factors due to geology and topographic effects by using digital elevation models (DEM); b) assign and classify the vulnerability of the building stock through the cadastral database; c) include the soil-structure resonance effect in the vulnerability; as well as other improvements, always with the highest processing speed. Therefore, any stakeholder or emergency planner will be able to make decisions in a very short time by handling the program.

## 2. Methodology

### 2.1 GIS environment and databases (DB)

On the one hand, SISMOTOOL is coded to be part of the ArcGIS toolbar (Figure 1) because, nowadays, it is one of the world's most powerful mapping and analytics software. The current version works through an Add-in type ArcGIS customization; actually, VB.NET language and the ArcObjects software development kit integrated into a Microsoft Visual Studio programming environment are used to write the code of the tool. VB.NET has been chosen due to the combination of simplicity of use and speed compared to other development language options such as Java, Python or

C++. Since ArcGIS is a commercial software, it is not unusual that stakeholders and emergency planners in the municipalities have it installed in their office and have expertise in its use; and even more, SISMOTOOL extension is an open-source code and, therefore, the source code of the Visual Studio project is provided, i.e. it can be specifically adapted either any user or a free GIS (for instance, QGIS).

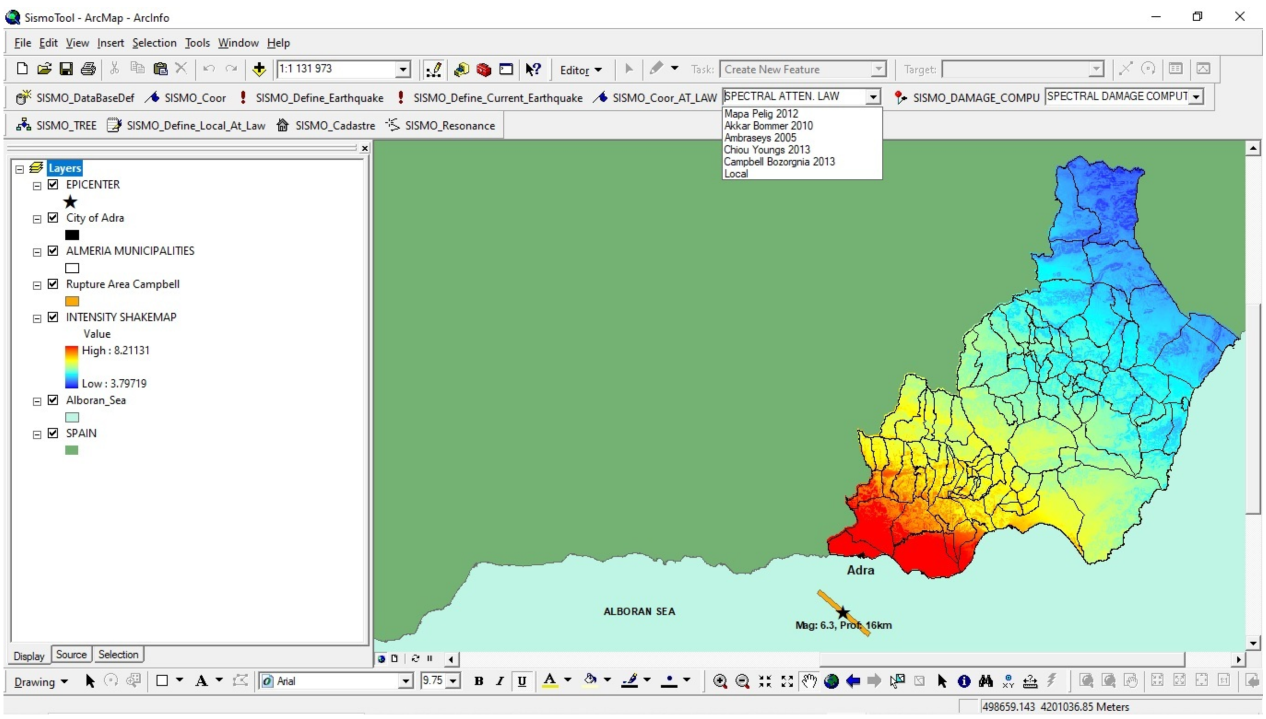


**Figure 1**. SISMOTOOL toolbar within the ArcGIS framework showing an intensity shakemap (1910 Adra earthquake) for Almeria (Spain)

On the other hand, some of the main advantages of using ArcGIS is to automatically prepare all the needed DB for an accurate earthquake losses estimation; in other words: Seismic catalogue DB [16], Quaternary faults DB of Iberia [17], Hydrographic network and DEM [18], Cadastral information [19] and Population information [20] could be directly incorporated into the analysis.

The user can interact and process these DBs through various forms that are displayed through the toolbar, such as the one corresponding to the logic tree calculation (section 2.2.7) shown in Figure 2.

## 2.2 Earthquake loss estimation (ELE) methodology implemented in SISMOTOOL

The main sequence of running SISMOTOOL is shown in Figure 3. To begin with, the user will introduce some data in every step through the toolbar (Figure 1) and then, execute within ArcGIS.

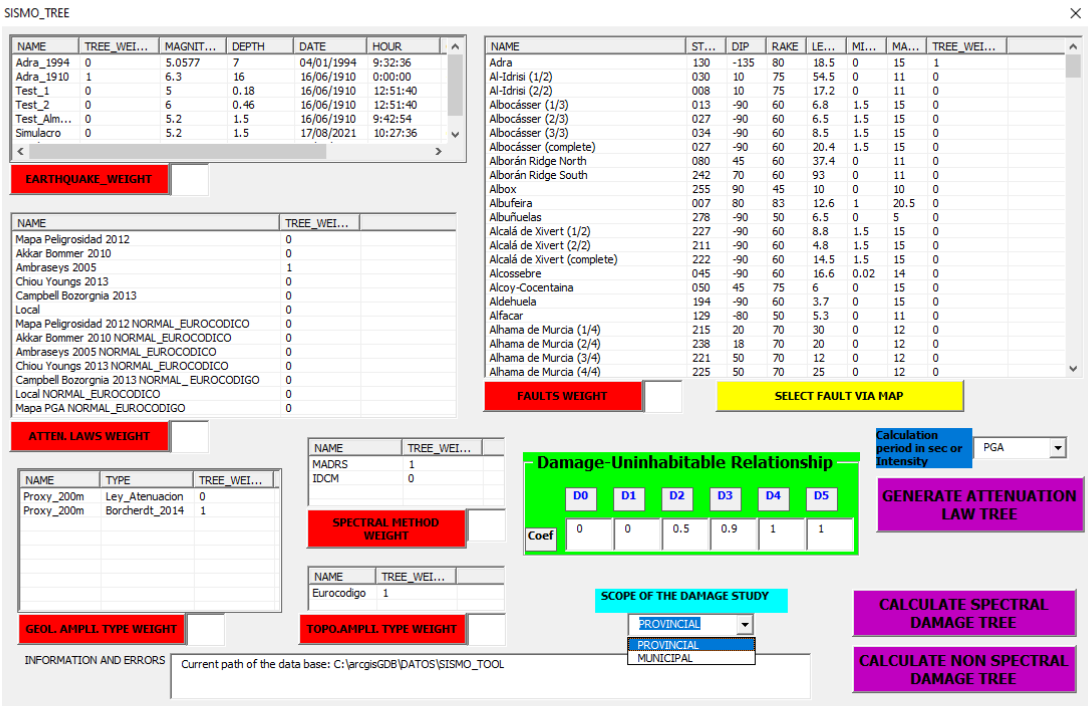


**Figure 2**. Example of one of the elements of the SISMOTOOL toolbar, used for logic tree calculation

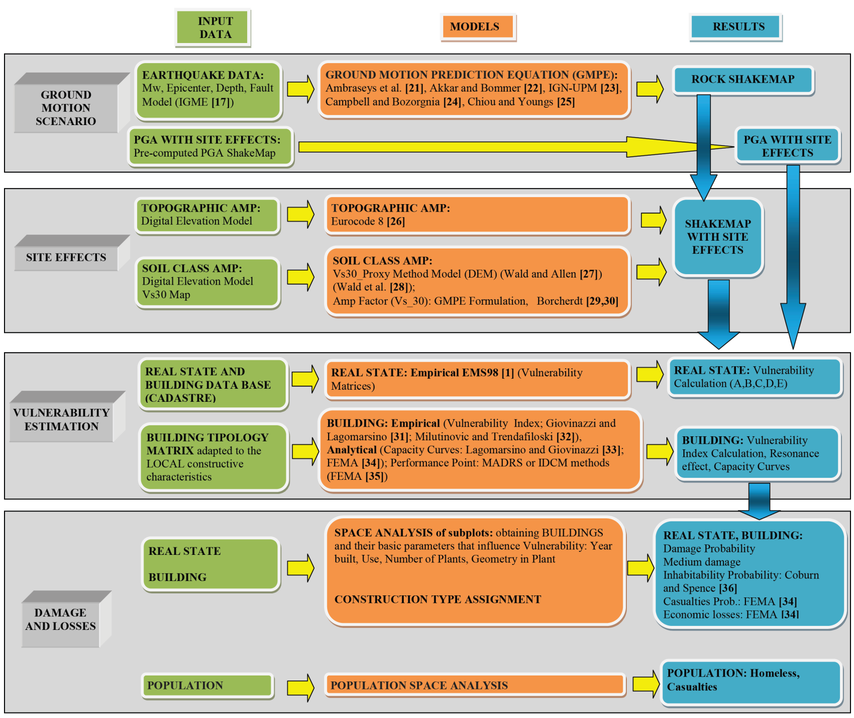


**Figure 3**. SISMOTOOL development and computation scheme

To aid in effective seismic emergency planning, results of damages and losses are calculated at the maximum available scale from the input data, at the building level and generating raster files with a spatial resolution of up to 5 m pixel (Figure 4).

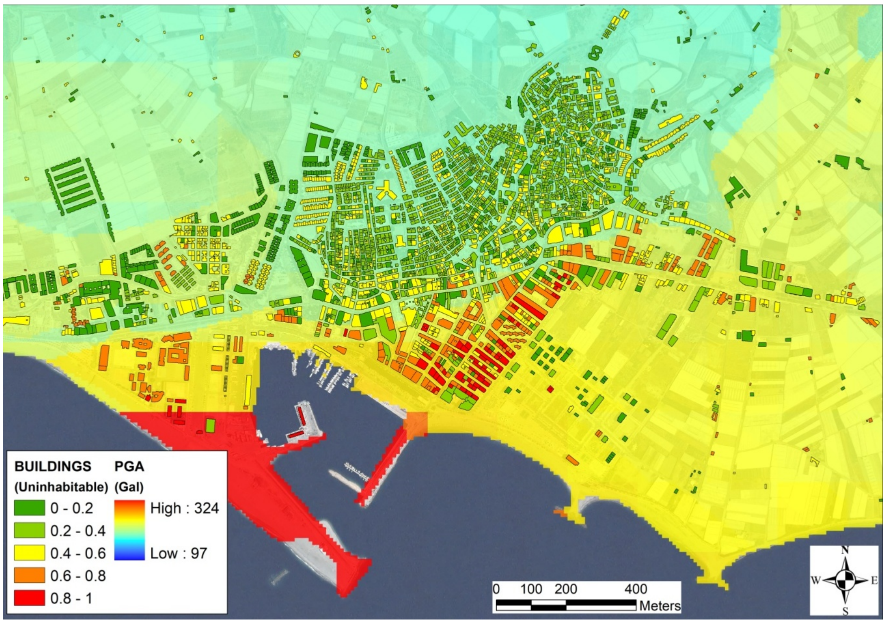


**Figure 4**. Simulation example obtained by SISMOTOOL for the Adra earthquake of 1910. The buildings colour represents the uninhabitability, on a base rater map that represents the PGA

Although the methodology could be understood at a glance from Figure 3, some procedures, specially developed or coded in SISMOTOOL, are highlighted below.

### 2.2.1 Ground motion scenarios

The first step in any ELE computation is the description of the seismic impact in terms of a shakemap. To do that, two options are implemented: deterministic scenario and pre-computed shakemap.

#### 2.2.1.1 Deterministic scenario

In the first option, the user can select the source parameters for a given earthquake (moment magnitude, latitude and longitude of the epicenter, focal depth or faulting type) from a pre-defined database of historical earthquakes. Additionally, a proprietary fault DB based on QAFI (Quaternary active faults DB of Iberia [17]) is integrated into the program (Figure 5). Therefore, the user can simulate any possible earthquake related to any of these faults and the rupture area will be estimated using the moment magnitude and the relationship given by Wells and Coppersmith [37]. The rupture area is spatially located in a plane parallel to the chosen fault plane and centered on the hypocenter which can be defined by the user through the epicentral coordinates and the focal depth; however, if the depth is unknown, this parameter will be automatically computed as the intersection of the fault plane with the vertical line from the epicenter. Additionally, a boundary condition is applied assuming that the calculated rupture area cannot get out from the earth's surface.

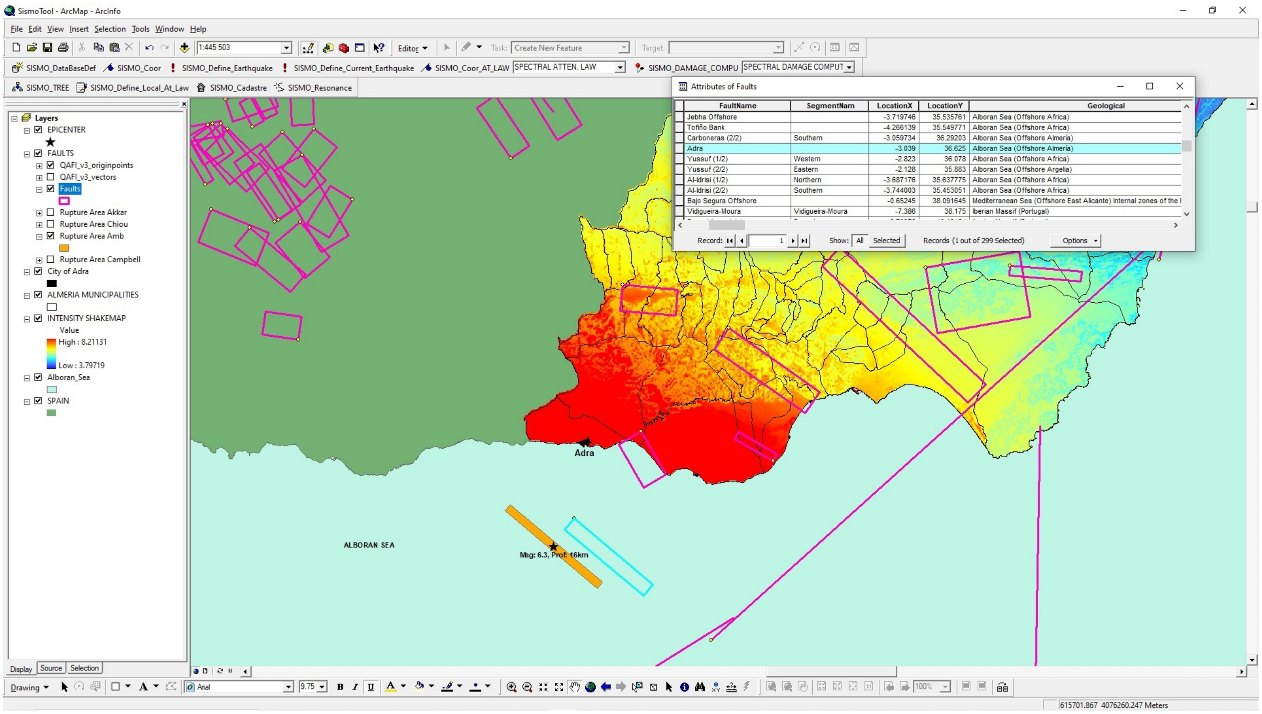


**Figure 5**. SISMOTOOL fault DB, generated with data from QAFI [17]