Seismic Risk Assessment for Regional Educational Systems
The Algarve Case Study

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ABSTRACT
An integrated seismic risk assessment methodology for regional educational systems is presented for the Algarve, the southernmost region of continental Portugal. The first stage of the presented study consisted in the collection of information referring to the regional educational system, which comprised the physical characterization of 311 school campuses, corresponding to 76541 students. The second stage of the study was devoted to the adoption and modifications on existing seismic risk assessment methodologies (Giovinazzi & Lagormarsino), adapted to national and regional constructional typologies. The third stage consisted in the simulation of physical damage estimates for each of the educational buildings for one reasonable earthquake scenario. The fourth, and final, stage consisted in the analysis of the educational system status as a whole, drawing some conclusions with respect to the operationality of the regional educational system immediately after the earthquake and the statistics of the prospective damage state.

Keywords: schools, EMS-98, damage assessment methodologies, educational system, GIS, earthquake simulator

1. INTRODUCTION

In the last decades, disasters have affected schools and university campuses, sometimes causing death and injuries but always imposing economic losses and disruption of educational continuity. "A potential earthquake can make schools inaccessible for long periods: quality of education can seriously be affected as a result of injury and death, or destruction of educational materials. It takes years to train teachers and educational staff." (in *http://www.riskred.org/schools/actionaidnepal.pdf*).

The particular importance of school buildings can be seen to derive from the conjunction of the following factors: schools are high occupancy buildings (structural collapse may result in unexpectedly high human casualty figures); high social relevance on a day-to-day basis; and, in the event of an earthquake, these facilities can be used as temporary shelters and/or as local centres for coordination of post-earthquake emergency activities. Probably to a greater extent than in other groups of buildings, individual schools can be seen to be part of geographically distributed systems – at municipal, regional or national levels – which, as such, may also be systemically affected. The present work tries to address the issue of risk assessment of educational systems, at regional level, namely in terms of the consequences for educational and post-earthquake (emergency) uses. On the other hand, schools are a part of urban areas, and, as such, these may be affected by damage in other groups of buildings (e.g., common building stock, such as housing or offices) or infrastructures. The interaction between the educational system and other urban systems is also addressed in this paper.

The most relevant purpose of this study is to provide a sense of the impact on a particular regional educational system, through quantitative loss estimation, using risk assessment modelling tools developed for the case study of the southern region of Portugal, the Algarve, incidentally the most earthquake prone region of continental Portugal.

2. THE RESEARCH: LOCATION, DATA COLLECTION AND ANALYSIS

2.1. Location

The Algarve region is located in the south of Portugal, comprising an area of 4989 km^2, 16 municipalities and a total of 430000 inhabitants (INE, 2008). Due to the steady growth of the tourism sector over the past 40 years, the Algarve now presents a strong contrast between the coastal areas (where the main urban centres are located and about 70% of the population lives) and the mountainous, inland, areas, with sparse population. Tourism brings in more than 3 million visitors each year, which means that the population triples at certain times of the year (EUROSTAT, 2009).

The Algarve region experienced large and destructive earthquakes in 1755, 1858 or 1969 (see Figure 1) and future large earthquakes are a certainty. Earthquake hazard results from two distinct scenarios: (i) large magnitude, interplate, earthquakes, with epicentres located near the Azores – Gibraltar fault; and (ii) moderate magnitude, intraplate, earthquakes generated in faults within or near Algarve mainland. Tsunami risks are also important for the interplate earthquake scenario.

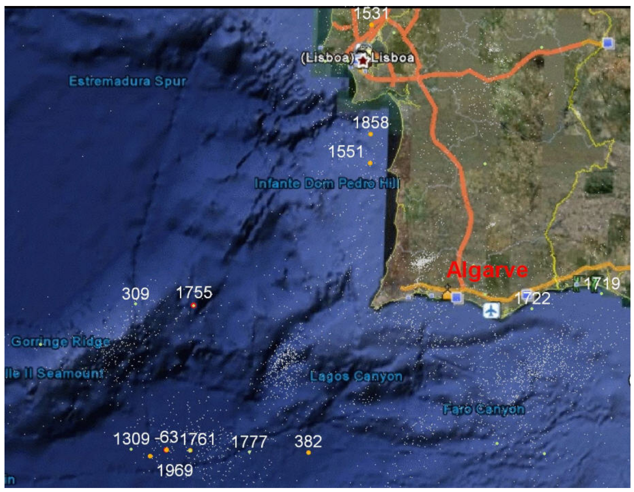

Figure 1. Historical earthquake epicentres

With the support of national and local entities (municipalities, regional directorates, etc.) the Portuguese National Authority of Civil Protection (acronym ANPC) has ordered a GIS-based seismic (and tsunami) simulator for the Algarve region. This simulator was developed along the past three years and was developed in order to provide scenario analyses and become a useful training tool addressed to the national and regional Civil Protection agencies. The simulator comprises the seismic hazard module, the vulnerability and loss estimation modules and each module includes databases and geo-referenced layers of data. ICIST/IST was commissioned, amongst other tasks, the characterization of the educational building stock and corresponding seismic vulnerability.

2.2. Data collection

The first phase of this study focused on the build up of a database comprising all characteristics of educational campuses (and buildings) relevant to seismic risk assessment. To effectively check and evaluate the characteristics of schools buildings an online survey portal - *www.escolariscos.eu* (schools at risk) – was launched to gather all relevant data.

Field data collection, which took approximately one year to be finished, consisted in a direct observation of each of the campuses through a combined effort of all 16 municipalities, the Algarve Regional Directorate of Education (DREALG, Portuguese acronym) and ICIST/IST research team.

From a total of 378 schools included on the website/database, direct observation data was collected for

311 campuses, from kindergarten to universities (including 270 public and 41 private owned schools), with a geographic distribution depicted in Figure 2.

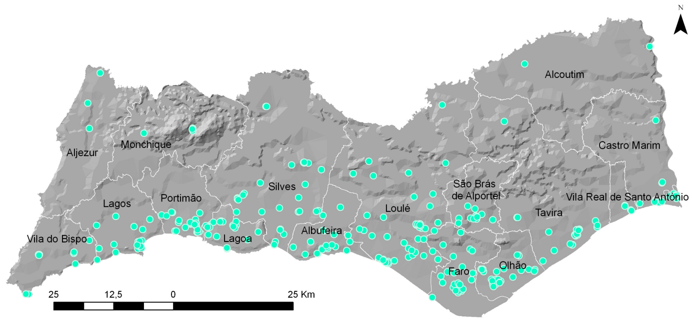

Figure 2. Location of school and university campuses.

The website portal *www.escolariscos.eu* is basically an online checklist of observable items, designed to evaluate each educational campus and corresponding school buildings. Generally speaking, each campus was described by three forms: (i) campus; (ii) building; and (iii) gymnasium forms.

The campus form, exemplified in Figure 3, comprised information on the educational level, address and location (GIS), number of buildings, existence of gymnasium, characteristics of the building plot and terrain, access and evacuation conditions, other natural hazards and number of students, teachers and remaining staff.

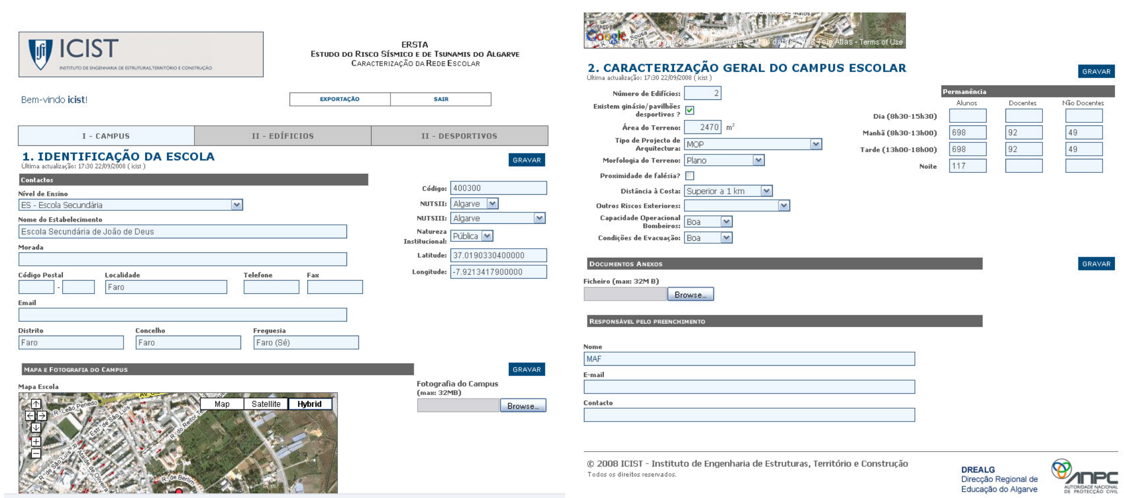

Figure 3. Example of campus sub-form (left – top; right – bottom).

The building form, exemplified in Figure 4, was actually made of as many sub-forms as the number of buildings. Each of these sub-forms comprised information on: number of storeys, area, typology of the architectural project, structural characteristics (reinforced concrete frame, dual frame-wall, wall structure, precast, masonry wall load bearing structure, etc.), state of conservation, date of design/construction (related to different series of enforced earthquake resistant structural design codes), structural irregularities and non-structural hazards. The gymnasium form follows the organization of the building sub-forms, with a more specific classification of the roof structure.

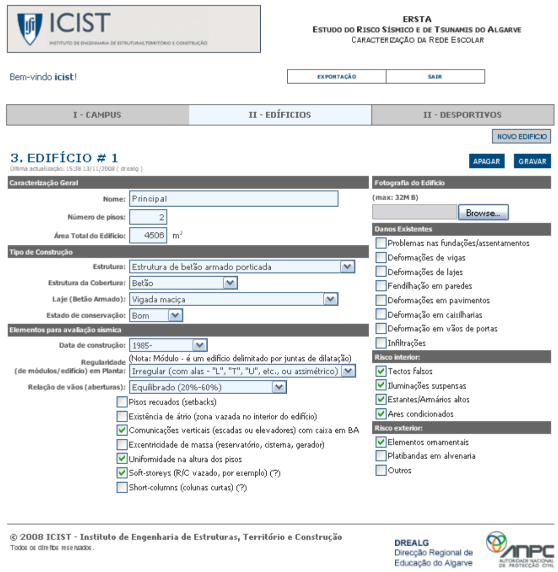

Figure 4. Example of building sub-form.

2.3. Brief survey analysis

The survey suggests that around 53% of the school buildings were built after 1983 and have 1-2 floors. Older buildings, built prior to 1960, represent about 23% of the database and regarding the state of conservation, 57% of school buildings are in "good" condition and 2% in "bad" condition. The asymmetry of the floor plans, the presence of setbacks, short-columns and storeys with different heights (vertical irregularity) are very common, mainly in the more recent buildings, and are known to increase the overall building vulnerability. Another factor with a large representation (10%) corresponds to the buildings with large openings (soft-storeys) making the storey "weak" or "soft" and likely to lean or fall over in earthquakes.

3. SCHOOL BUILDING DAMAGE ASSESSMENT

3.1. Vulnerability index based on the EMS-98 scale

The European Macroseismic Scale (EMS-98) (Grünthal, 1998) contains a detailed definition of the different building typologies and the damage distribution related to the earthquake severity (intensity), as well as a detailed description of each degree of damage – in load bearing masonry and reinforced concrete buildings. In this study the vulnerability model used the concepts developed by Giovinazzi and Lagomarsino (2004), where a vulnerability index (V_I*) is defined taking into account the different building typologies with similar behaviour during an event.

The school buildings were classified in different groups characterized by a similar seismic behaviour and were grouped in 4 age categories, related to the dates of enforcement of increasingly stringent seismic codes in Portugal (see Table 3.1). A vulnerability index approaching 1.0 indicates a more vulnerable structure, while this index approaches 0 for low vulnerability structures or the high-code designed structures.

Table 3.1. Vulnerability index for typologies and periods of construction of Algarve according to the seismic design level.

Period of constru-ction	Portuguese code	Seismic design level	Vulnerability index (V_I^*)										
			M5	M6	RC4-	RC4	RC4+	RC5	RC1	RC2-	RC2, W	RC2+	Precast concrete
< 1960	----	Pre-code	0.74	0.616	0.553				0.644		0.447		0.66
1960-1969	RSCS (1958)	Low-code	0.74	0.616		0.544				0.553	0.447		0.66
1969-1985	RSEP/REBA (1968)	Medium-code					0.464				0.447		0.66
1985 until now	RSA/REBAP (1983)	High-code						0.384			0.447	0.393	0.553

*Note: M – masonry, RC – reinforced concrete and W – wood

The typological vulnerability index V_I^* calculated for each building typology could be increased or decreased by a group of behaviour modifiers (Figure 5) that were identified during the field inspection, some of which are referred to in § 2.3.

Figure 5. Example of some factors able to modify seismic behaviour; left– soft-storey; centre – setbacks; right – plan asymmetry.

3.2. Earthquake simulator and damage estimation

The simulator developed for the Algarve region includes attenuation laws, soil characterization according to EC8 prescriptions, population data and information related with lifelines (water, power network, transportation, health facilities, etc).

As the simulator is able to generate several earthquake scenarios and estimate the seismic intensities at any location of the territory under analysis, we are able to calculate the expected damage of school structures, according to the following equation:

$$\mu_D = 2.452\left(1 + tanh\left(\frac{I + 5.604V_I - 12.19}{1.797}\right)\right) \tag{3.1}$$

where μ_D means the mean damage grade (grade 1 = slight, grade 2 = moderate, grade 3 = heavy, grade 4 = very heavy and grade 5 = collapse), I is the intensity and V_I the vulnerability index.

4. ASSESSMENT OF THE EFFECTS OF THE EARTHQUAKE ON EDUCATIONAL SYSTEM

Although natural disasters may only last a short period, its impact can take months or even years.

Some electrical facilities and local water-distribution systems are expected to be inoperative, as some roads can be damaged or blocked causing a disruption to the whole urban system: distribution of food, water, lack of health services and school interruption are some examples of what could be affected during critical days or months. Earthquake planning scenarios are designed to give a realistic image of an anticipated earthquake and could be an important tool to identify which strategies must be taken into account. Some examples of the simulator results are subsequently presented to stress the former ideas.

A magnitude 6.3 earthquake scenario was selected on the Portimão Fault and the simulator estimated that about 1000 people would be killed, over 13000 buildings would suffer at least some damage causing injuries and homeless, nearly 20 schools would be damaged and infrastructures, including roads, telecommunications (about 20%), power lines (28% of the total population without power) and water systems would be affected, causing a long-lasting social and economic impact (Figures 6 and 7).

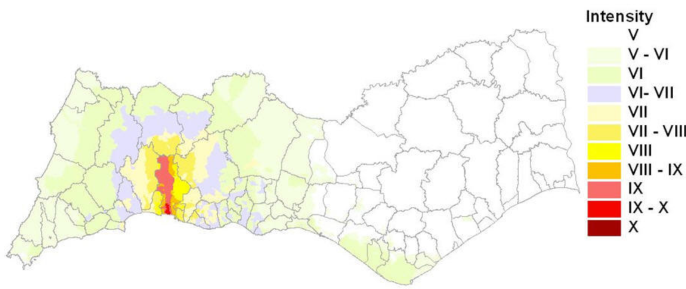

Figure 6. Algarve region and intensities generated by the Portimão fault (M6.3) - maximum intensity of IX-X in Portimão.

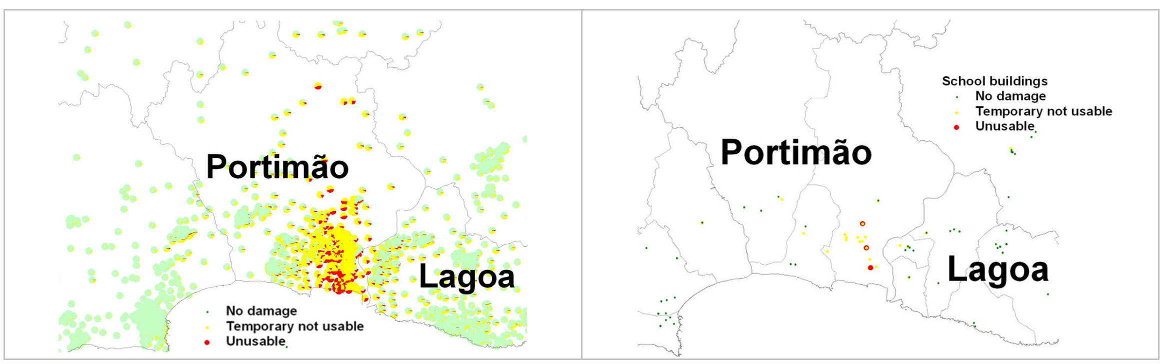

Figure 7. Damages to the building stock by census tract (left) and to the school buildings (right).

The medium or long-term educational system disruption will be not only a consequence of the damaged verified on the school buildings but also comes from damage to the building stock, water distribution system or the need to relocate people in other localities after the event.

It appears clearly that when analysing the entire system - the whole urban functions – the knowledge/awareness of the school buildings performance is not sufficient to conclude about the maintenance of educational system; direct and indirect educational interruption should be considered. The village of Onna (L'Aquila earthquake 2009) is an example of this propagation effects (physical and functional); it was severely affected with collapse or partial collapse of a large proportion of its structures. Although a one-storey recently built school performed extremely well, the high level of destruction of almost surrounding buildings, made the school lose its educational function as well the emergency function, due to the high post-earthquake disruption (damaged roads, housing, utilities, etc).

Source: www.telegraph.co.uk/news/picturegalleries

Figure 8. Scuola dell'Infanzia Regina Margherita (left). Onna overview after the L'Aquila earthquake.

4.1. Usability assessment and risk management

Post-earthquake usability assessment is commonly aimed to evaluate the possible short term use of the damaged buildings (Goretti *et al.*, 2006). After an event, safety inspections based on visual and data easily collected, identify the buildings that can be used in case of aftershocks, guaranteeing the safety of the citizens. In this study, and prior a future event, it is also evaluated the performance of the existing school buildings using a scenario earthquake with a probability of occurrence corresponding to the European and national codes (Eurocode 8, EN 1998-1, and National Annex, NP EN 1998-1). This type of analysis provides an excellent opportunity for municipalities and DREALG know how to important and prepared the schools are for earthquakes and start working on their risk reduction programs.

According to the mean damage grade (D) obtained from the procedure described in § 3, it was suggested which schools can maintain in operation of education immediately (D<1) or after some less intrusive works of rehabilitation/strengthening (1≤D<2, non-structural damage) or more intrusive and time consuming (2≤D<3), and even those who will have to be demolished, due to high structural, non-structural or geotechnical risk for human life. Similarly, a level of damage was established (D<1.5) below which the school buildings may serve to centralize the operations of emergency or for the accommodation of homeless (Figure 9) for a short period.

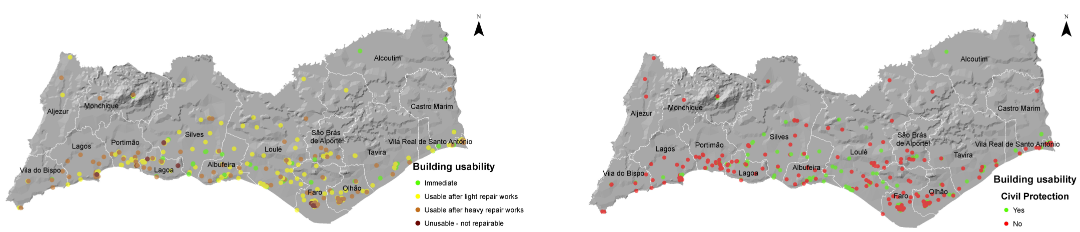

Figure 9. School buildings usability. Educational purposes (left); and civil protection (right).

Table 4.1. Consequences to the educational continuity and emergency response

Educational	Usable	16%
	Usable after minor repair works	57%
	Usable after heavy repair works	24%
	Demolition	3%
Civil Protection	Yes	51%
	No	49%

As it is widely acknowledged non-structural damages can block evacuation with furniture blocking passage or could kill or injure people; the labs, electronics and kitchen equipments can cause fires, resulting in serious injuries. Non-structural damages could impair the educational continuity or the level of safety conferred by seismic building codes. As shown in Table 4.1 more than 50% of the regional school buildings could suffer slight to moderate damages, affecting for a certain period the educational continuity.

Building codes requirements lies just above life safety, not considering the immediate occupancy or building operationally requirements, both to staff, students and the community and this is an important topic that should be further studied.

If the propagation effects, physical and functional, of the area of influence of each school campus are considered, the figures shown in Table 4.1 will certainly increase significantly as work in progress has shown for a first analysis (Francisco Mota de Sá and Mónica Amaral Ferreira, personal communication).

5. TO SUM UP

In Algarve region school buildings probably will face some problems to survive intact and in usable conditions after an earthquake. The impact of school closure could contribute significantly to a economic and social breakdown.

What is important to glean from this study is that the propagation effects are critical - infrastructure systems are extremely vulnerable and their failure can result in the disruption of other facilities and activities - and should be considered in simulators. Risk reductions plans need to look to the school system as a whole and not as a summary of individual contributions to minimize earthquake disruption.

Ongoing studies will enhance the systemic nature of this problem allowing a more robust hierarchy scale on the mitigation strategy.

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