VULNERABILITY ASSESSMENT IN EDUCATIONAL BUILDINGS – INFERENCE OF EARTHQUAKE RISK. A METHODOLOGY BASED ON SCHOOL DAMAGE IN THE JULY 9, 1998, FAIAL EARTHQUAKE IN THE AZORES

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ABSTRACT :

On July 9, 1998, an earthquake M6.2 struck Faial, Pico and São Jorge islands in the Azores archipelago, leading to 8 human casualties. In Faial Island, about 2000 buildings, mostly single-family housing units, were partially destroyed or completely collapsed; thousands of inhabitants were made homeless. The use of school buildings for temporary housing was, nevertheless, possible, due to the lesser extent of damage in some of Faial's schools. Vulnerability assessment of school buildings was performed using a methodology based on the works of Giovinazzi and Lagomarsino and a comparison is presented between observed (in 1998) and predicted building damage. This methodology was aimed at the estimation of MDG (Mean Damage Grade) as a cross function of vulnerability and intensity. The original procedure was extended to the prediction of the effects on post-earthquake school use (possibility of immediate use, duration of repair and retrofitting works and demolition) and human losses. This extension was based on information collected in 1998.
This modified seismic vulnerability assessment methodology was also used for the prospective building damage assessment for different earthquake scenarios. The possibilities of using such results for the definition of retrofitting and land use policies are also presented.

KEYWORDS: SCHOOL BUILDINGS, ASSESSMENT, AZORES

1. INTRODUCTION

The present study starts with a retrospective of damage distribution in 21 educational buildings as a consequence of the 1998 Faial earthquake. Damage distribution has shown a strong dependence on the existing structural solution (building material and structural typology) and a consistent pattern of non-structural damage was clearly identified - such as dislocated roof tiles and damage to earth-retaining walls –.
An existing earthquake damage assessment methodology, based on the European Macroseismic Scale (EMS-98), is briefly presented. This methodology was modified introducing aggravating and de-aggravating factors to take into account structural regularity, number of storeys, conservation condition, short columns and insufficient seismic joint widths. Different versions of earthquake-resistant design codes were also considered in the model by comparing the building date of construction with the dates that these codes were enforced. School damage computed through this modified methodology was favourably compared to observed damage in the 9th of July, 1998, Faial earthquake.
More recently, in 2007, a complete survey was performed in the Faial Island, leading to a new school inventory. The modified earthquake damage assessment methodology was then applied considering the maximum intensity (EMS) observed in the 20th century and the current inventory of school buildings in Faial. Results, expressed in terms of the expected MDG (mean damage grade) are presented and some conclusions are drawn.

2. DAMAGES ON SCHOOL BUILDINGS AFTER THE JULY 9, 1998, EARTHQUAKE

In the aftermath of the quake, a team from Instituto Superior Técnico (IST) have visited all the 21 school buildings of Faial and a quick and correct building evaluation was made for the retrieval of normal living conditions. The report (Azevedo *et al.*, 1998) shows little damage was detected in all schools, apart from the collapse of an exterior wall in a kindergarten (Figure 1) and two schools considered potentially dangerous were demolished (Espalhafatos and Ribeira Funda).

Figure 1 Salão kindergarten partial collapse. Azorean traditional construction type.

Table 1 resumes the damages occurred after the 1998 event taken in a special study carried out by the Council of OECD (Proença, 2004).
More recently, in 2007 a new survey was developed to evaluate the actual level of security and vulnerability (Proença *et al.*, 2008) of Faial school buildings (23 schools). This survey contains detailed information about epoch and types of constructions, number of storeys, presence of short-columns, story height irregularity, state of conservation and plan regularity. These parameters were used to calculate the mean damage grade (MDG) according to the methodology based on the European Macroseismic Scale (EMS-98) (Grünthal, 1998).

Table 1: Damage in 1998 earthquake (school buildings, Faial Island)

Location (address)	Intensity (MMI	Structural solution	Building quality	Typology EMS-98	Construction date	Conservation condition	# of storeys	Structural damage	Non-structural damage	Other damage	Use
Flamengos	VII	Masonry wall	High	M5-M6	1930	Good	1	Corner cracks Sligth cracking in partition walls	Dislocated roof tiles	Damage in entrance pediment Damage in external retaining walls	Use after minor repairs
Almoxarife	VII	Frame RC	High	RC2+	1990	Good	2, partially	Cracks in columns Damage near expansion joint (pounding ?)	Dislocated roof tiles Sligth cracking in partition and external walls	Damage in external retaining walls	Use after minor repairs
Pedro Miguel	VII	Frame RC	High	RC2	1980	Good	2, partially	None	None	None	Immediate use
Ribeirinha	VIII	Frame RC	High	RC2	1980	Good	1	Roof beams (pounding ?)	Dislocated roof tiles Sligth cracking in partition and external walls	Damage in external retaining walls	Use after moderate repairs
Espalhafatos	IX		High	M5-M6	1950	Average	1	Damage at corners with separation between masonry and RC elements Damage at the column bases Cracks in external walls	Cracking in partition and external walls Floor settlement	Damage in external retaining walls	Use after extensive repairs
Salão	IX		High	M5-M6	1950	Average	1	Damage at the columns	Cracking in partition and external walls Cracking in the connection between floors and walls	Damage in external retaining walls	Use after moderate repairs
Salão (kindergarten)	IX	Masonry wall	Medium	M2	1920	Average	1	External wall collapse	General damage	General damage	No use, demolish
Cedros	VI		High	M5-M6	1950	Good	2	None	Cracking in partition and external walls	Cracking in external retaining walls	Immediate use
Cascalho	VI	Frame RC	High	RC2	1980	Good	1	Sligth cracking in RC roof beams	Sligth cracking in partition walls		Immediate use
Ribeira Funda	VII	Masonry wall	High	M5	1940	Average	2	Extensive cracking in external walls	Cracking in partition walls	Damage in external retaining walls	No use, possible demolition
Praia do Norte	VI	Frame RC	High	RC2	1980	Good	1	None	Sligth cracking in partition walls		Immediate use
Capelo	V		High	M5-M6	1950	Good	1	None	None	None	Immediate use
Lombega	VII		High	M5-M6	1950	Good	1	None	None	None	Immediate use
Castelo Branco (Carreira)	VI		High	M5-M6	1950	Average	1	None	Cracking in partition walls Dislocated roof tiles Stucco and plaster fall-off	None	Use after moderate repairs
Castelo Branco (Farrobim)	VI		High	M6	1960	Good	1	None	None	None	Immediate use
Feiteira (Travessa do Algar)	VI		High	RC2	1980	Good	2, partially	None	None	Sligth damage in external retaining walls	Immediate use
Feiteira (Rua da Portela)	VI		High	M6	1950	Good	1	None	None	Damage in electrical instalations Damage in external retaining walls	Use after minor repairs
Horta (Pasteleiro)	VI	Frame RC	High	RC2	1980	Good	2, partially	None	None	None	Immediate use
Horta (Rua Cônsul Dabney)	VI	Frame RC	High	RC2	1980	Good	2, partially	None	None	None	Immediate use
Horta (Coronel Silva Leal)	VI	Masonry wall	High	M5	1930	Average	2	Cracks in external and partition walls	Cracking in plaster ceilings	Damage in electrical instalations	Use after moderate repairs
Horta (Gaiatos)	VI	Frame RC	High	RC2-	1960	Good	2	None	Cracking in plaster ceilings	None	Use after minor repairs

3. MACROSEISMIC METHOD

Data collected after the earthquake helped in identifying and classifying the observed damage grades based on EMS-98. The EMS-98 includes six damage grades (D0 – no damage to D5 – destruction) based on the extension of structural and non structural damage in buildings. This information was valuable to compare the results obtained by the macroseismic method (Giovinazzi and Lagomarsino, 2004) with real damage observed.
Once characterized the type of structures, it is possible to differentiate the typological vulnerability index V_I for the specific building type and this index can be increased or decreased according to the behaviour factors recognized inside a building. The behaviour modifiers and respectively scores for reinforced concrete buildings (according to building code era) and masonry buildings introduced on this study are shown in Table 2 and 3.

Table 2 Behaviour modifiers and scores for masonry buildings

State of conservation	**Number of floors**	**Plan asymmetry**	**Story height irregularity**
Good: -0.04	1-2 storeys: -0.04	0.04	0.04
Reasonable: -0.02			
Bad: 0.04			

Table 3 Behaviour modifiers and scores for reinforced concrete buildings

Behaviour modifiers	**Low (1940-60)**	**Moderate (1961-83)**	**High (> 1983)**
State of conservation	Good: 0 Bad: 0.04	Good: 0 Bad: 0.02	Good: 0 Bad: 0
Number of floors (1-3)	-0.02	-0.02	-0.02
Plan asymmetry	0.04	0.02	0
Short-columns	0.02	0.01	0
Insufficient joints	0.04	0.03	0.02

Type of structures identified in Faial school buildings are: M1, M3, M5, M6, $RC2^-$, RC2 and $RC2^+$ (Grünthal, G., 1998, modified).
Finally a mean damage grade, μ_D, function of vulnerability index (V_I) and intensity (I) can be obtained and has been expressed as:

$$\mu_D = 2{,}5.\ (1 + \tanh\ (I + 6.25.V_i - 13.1) / 2.3) \qquad (3.1)$$

4. DAMAGE SCENARIOS

Two different scenario earthquakes were considered and computed with the following scheme: the first one simulates the July 9, 1998 earthquake (Faial earthquake) while the second scenario corresponds to the maximum intensities obtained in Faial during the late 20^{th} century, adapted from Nunes *et al.* (2005).
The ArcGIS software was used to create a GIS tool for managing the collected information and develop seismic risk scenarios.

4.1. Faial earthquake

The detailed scenario illustrated in Figure 2 shows different levels of earthquake intensity obtained from Faial event. With this intensity values and knowing each vulnerable index was possible to obtain results similar of the referenced from post-earthquake inspection data; a mean damage grade, μ_D=3 and μ_D=4, was obtained for the intensity VIII as observed after the earthquake. These two schools with mean damage grade equal to 3 and 4 consists in unreinforced masonry buildings with manufactured stone units and traditional constructions (rubble stone), respectively, having little resistance to lateral loading which increases the chances of collapse.

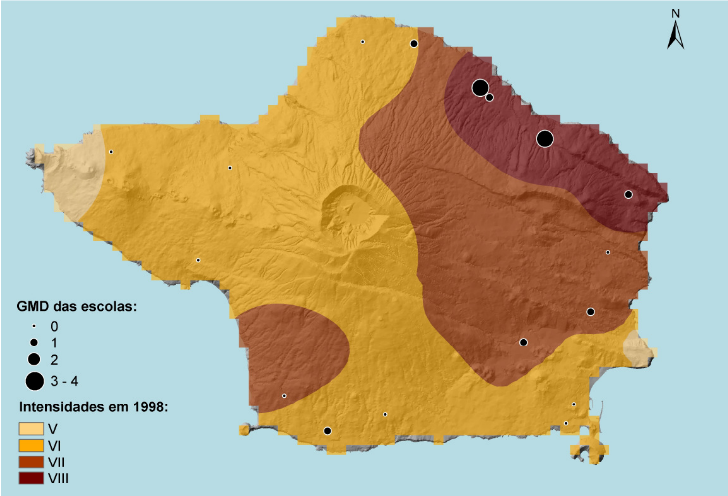

Figure 2 Isoseismal map of the 9 July 1998 Faial earthquake and mean damage grade

4.2. Earthquakes in the late 20th century

The largest 20th century earthquake in Faial (magnitude 5.6, intensity X) occurred in 1926 and destroyed part of Horta city.
Table 4 and Figure 3 refer the mean damage grade that could occur in each school building considering the maximum intensity for each locality.

Table 4 Mean damage grade to the maximum intensity in school buildings

School name	EMS-98 typology	State of preservation	Maximum intensity EMS-98	MDG
Flamengos	M3	Reasonable	X	**4**
Almoxarife	RC2+	Good	X	**2**
Pedro Miguel	RC2	Reasonable	IX	**1**
Ribeirinha	RC2	Reasonable	IX	**1**
Salão	M5	Reasonable	IX	**3**
Cedros - EB1/JI Prof Constantino Magno do Amaral	M6	Bad	VIII	**1**
Cascalho	RC2	Good	VIII	**1**
Praia do Norte	RC2	Reasonable	IX	**1**
Capelo (e P. Norte)	M5	Reasonable	VIII	**2**
Ribeira do Cabo - EB1/JI Capelo	RC2	Bad	VIII	**1**
Lombega	M5	Good	VII	**1**
Castelo Branco (Carreira)	M3	Reasonable	VII	**1**
Castelo Branco (Farrobim)	RC2	Reasonable	VII	**0**
Feteira (Travessa do Algar)	RC2	Reasonable	IX	**1**
Feteira (Rua da Portela) - Escola de Grotas	M5	Good	X	**3**
Horta (Pasteleiro)	RC2+	Good	X	**2**
EB1/JI Consul D'Abney	RC2	Reasonable	X	**2**
Horta (Coronel Silva Leal)	M3	Reasonable	X	**4**
Esc do Bairro das Pedreiras-Angustias	M5	Reasonable	X	**4**
EB da Lomba	M5	Good	X	**4**
Conservatorio Regional da Horta	M3	Reasonable	X	**4**
EB2, 3 Horta	M5	Reasonable	X	**4**
ES Manuel Arriaga	RC2-	Bad	X	**4**
EB1/JI Vista Alegre	RC2+	Reasonable	X	**2**

The city of Horta and considering a maximum intensity X must be expected very heavy damages (μ_D=4, heavy structural damage and very heavy non-structural damage) due to a high percentage of buildings of high vulnerability. We conclude that both the variation in building types as well as local soil conditions significantly affect the mean damage grade and should be taken into account in damage scenario modelling.

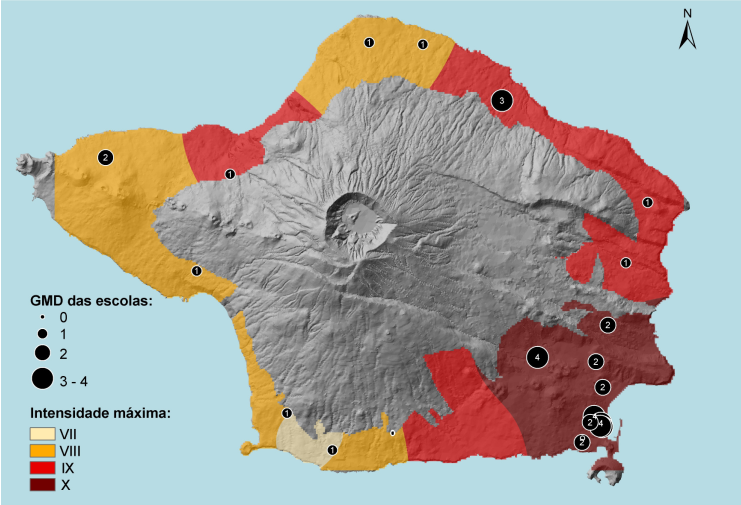

Figure 3 Mean damage grade assuming maximum intensities

5. DISCUSSION

Earthquakes have always shaken the Azores islands causing serious damages, deaths, injuries and homeless. Earthquakes are a particular concern for schools with their large concentrations of children in confined spaces.
In recent years, there have been deadly school collapses after earthquakes in Italy, Algeria, Morocco and Turkey. Most notably, in Pakistan on Oct. 8, 2005, at least 17,000 children died as more than 7,000 schools collapsed after a powerful shook. The recent quake that struck Sichuan province on May 12, 2008, destroyed more than 7,000 classrooms and an estimated 10,000 students are believed to have died due to shoddy school construction:

- unreinforced masonry construction or nonductile concrete construction (Global Risk Miyamoto, 2008);
- inadequate steel reinforcement was used in the concrete columns to support schools;
- school's precast, hollow core concrete slab floors and walls did not appear to be securely joined together.

All this practices should be analysed, reviewed and the application of technical knowledge for retrofitting or strengthening different type of structures is imperative to school buildings, which after a disaster can be used as an emergency shelter, emergency relief or distribution centre.
This simple methodology of damage assessment it's a first step to start describing strategies and programmes for making schools resistant and safety for earthquake shaking in Azores and protect the students from injury or death, and reduce structural damage to the building. The population of Horta city rounds 6500 inhabitants more than 40 percent of the total Faial population. If an earthquake like the 1926 occurs, the city could be severely damaged. Is important to the community decision makers know the risk and the level of vulnerabilities as to prepare and invest in mitigation measures to reduce losses.

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REFERENCES

Azevedo, J., Bento, R., Guerreiro, L., Lopes, M. and Proença, J. (1998). Missão do IST ao Faial e Pico na

Sequência do Sismo de 9 de Julho de 1998. Inspecção de Escolas e Igrejas. 1º Relatório. In Portuguese. Technical Report ICIST DT Nº 8/98, Lisbon, July of 1998.

Giovinazzi, S. and Lagomarsino, S. (2004). Macroseismic Method for the Vulnerability Assessment of Buildings. Proceedings of 13th World Conference on Earthquake Engineering, Vancouver, B.C , Vancouver, Canada.

Grünthal, G. (1998). European Macroseismic Scale European Centre of Geodynamic & Seismology, Luxemburg, 15.

Miyamoto (2008). Sichuan, China M8 Field Investigation Report Released

Nunes, J.C.; Lopes, V.M.; Almeida, M.; Laranjeira, P.T. and Lima, E.A. (2005). Intensidades sísmicas no século XX na Região dos Açores: Caracterização e implicações (in Portuguese). Proceedings of the 4th National Symposium o Meteorology and Geophysics, APMG.

Proença; J.M. (2004). Damage in the 1998 Faial Earthquake in the Azores Islands, Portugal; p. 131-139; Keeping Schools Safe in Earthquakes, OECD publication, Paris, August of 2004.

Proença, J.M. and Ferreira, M.A. (2008). Damage inflicted to the school facilities in the Faial island. A retrospective and prospective analysis. Sismo 1998 - Açores. Uma década depois. Editors C. S. Oliveira, Aníbal Costa and João C. Nunes, Governo dos Açores/SPRHI, S.A.