

CHAPTER

8

**DAMAGE IN SCHOOLS
IN THE 1998 FAIAL EARTHQUAKE
IN THE AZORES ISLANDS, PORTUGAL**

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Abstract: On 9 July 1998, an earthquake struck the islands of Faial and Pico in Portugal, killing eight people and leaving 1 000 homeless. Following the earthquake, 21 educational buildings were inspected in an attempt to establish the correlation between general building classification factors – structure, quality, conservation condition and number of storeys – and the buildings' damage state and post-event use. This paper presents the inspection results.

Introduction

Portugal is located in a volatile seismic area, where both intraplate and interplate tectonic events have caused significant devastation over the centuries. An *interplate* earthquake, the epicentre of which is located between the Eurasian and the African tectonic plates, led to the 1755 Lisbon earthquake, which had an estimated magnitude of M8.5 to M9.0, and to other seismic occurrences. Interplate earthquakes are characterised by very large magnitudes and large focal distances; for those that affect Portugal, the epicentre is typically located in the Atlantic Ocean, southwest of the Algarve. An *intraplate* earthquake is generated in any of the fault complexes within the continental plate, such as the lower Tagus fault complex. Intraplate events led to the 1531 Lisbon (maximum MMI = IX) and the 1909 Benavente earthquakes (maximum MMI = IX). Intraplate events are characterised by large magnitudes (typically M6 to M7) and small focal distances to inhabited areas.

The Azores Islands have experienced a number of seismic events, as the archipelago is located near the confluence of the American, Eurasian and African plates. The 1998 Faial earthquake was the most recent significant earthquake in the Azores.

The 1998 Faial earthquake

On 9 July 1998, at 05:19 local time, an earthquake of magnitude M6.2 occurred in the strait between the islands of Faial and Pico in the Azorean archipelago at 38.33°N and 28.07°W. The epicentre was located at sea approximately 5 km from the island of Faial and 15 km from its capital, Horta. The earthquake was felt on most of the Azores Islands and led to significant destruction, mostly on Faial Island, where it reached an intensity of VIII (MMI). Eight people were killed and approximately 1 000 were left homeless. Figure 8.1 shows the location of the epicentre and the isoseismals for the most affected islands of Faial (to the west) and Pico (to the east).

These two islands have experienced a number of natural disasters in the past. The 1926 Horta earthquake destroyed part of Horta; volcanic eruptions occurred in 1957 in Capelinhos, which is located on the western tip of Faial; a series of minor-to-moderate earthquakes struck the islands of Pico and S. Jorge in 1973; and more recently, an earthquake shook the nearby island of Terceira in 1980, although it did not cause significant damage.

In the aftermath of the 1998 Faial earthquake, a team from the Institute of Structures, Territory and Construction Engineering at the Higher Technical Institute (ICIST/IST) in Lisbon completed damage assessments of religious and educational buildings on the

islands of Faial and Pico. A total of 21 educational buildings were inspected on the island of Faial (Azevedo *et al.*, 1998).

Figure 8.1. Epicentre location and isoseismals chart for 9 July 1998 Faial earthquake

(adapted from Nunes *et al.* (1998) and Oliveira (1999))



Classification of educational buildings

Educational buildings were classified in terms of the structural solution, building quality, conservation condition and number of storeys.

Building structures were classified as follows:

- The *masonry wall* structural type corresponded to a local, traditional construction method, which uses thick external block masonry walls, generally made from loose rock blocks with small mortar quantities, with light internal masonry walls and a timber roof structure.
- The *early reinforced-concrete* structures comprised thick external block masonry walls (with mortar) and discrete reinforced-concrete elements such as columns (particularly at corners) and lintels.
- The *frame reinforced-concrete* and *frame reinforced-concrete with reinforced-concrete wall* constructions are common structural solutions and comprise reinforced-concrete frames (continuous beam and column) with reinforced-concrete shear walls.

The *building quality* and workmanship varied from medium to high.

The *building conservation condition* ranged from average to good, depending on the frequency and thoroughness of maintenance operations.

The *number of storeys* varied from single storey to two storeys.

Table 8.1 summarises the classification of educational buildings that were inspected by ICIST/IST.

Figure 8.2 – a two classroom, one-storey, early reinforced-concrete school in Espalhafatos – shows one of the most common solutions for educational buildings. The school building design and construction is similar to that found in Salão, Capelo, Lombega and Feiteira (Rua da Portela).

Figure 8.2. Overview of school at Espalhafatos



Earthquake damage and use classification

In addition to the building classification fields, Table 8.1 also summarises the most important conclusions of the assessment in terms of the educational buildings' damage state and post-event use. Figures 8.3 to 8.8 show some typical damage situations. The effects of the earthquake were assessed using the following three *damage* categories:

- *Structural damage*. Damage to structural, vertical and horizontal load-carrying elements.
- *Non-structural damage*. Damage to non-structural or secondary structural components.
- *Other damage*. Damage to installations and adjacent earth-retaining structures.

The *post-event use* of the building was one of the most important elements of the ICIST/IST inspection. Immediate use was important as many school buildings provided shelter for those who had lost homes in the earthquake. Medium-term use was also relevant as school activities were scheduled to begin about two months after the earthquake. The use classification considered:

- *Immediate use*. Inexistent or negligible damage.
- *Use after minor repairs*. Generally slight to medium damage to non-structural components and installations.
- *Use after moderate repairs*. Slight damage to structural components and/or severe damage to non-structural components and installations.
- *No use*. Demolition.

Table 8.1. Educational building classification, earthquake damage and use classification

Location	Intensity (MMI)	Structural solution	Building quality	Conservation condition	No. of storeys	Structural damage	Non-structural damage	Other damage	Use
Famengos	V-VI	Masonry wall	High	Good	1	Corner cracks and slight cracking in partition walls	Dislocated roof tiles	Damage in entrance pediment and damage in external retaining walls	Use after minor repairs
Almoarifxe	V-VI	Frame and wall (7) reinforced concrete	High	Good	2, partially	Cracks in columns and damage near expansion joint (pounding?)	Dislocated roof tiles and slight cracking in partition and external walls	Damage in external retaining walls	Use after minor repairs
Pedro Miguel	V-VI	Frame and wall (7) reinforced concrete	High	Good	2, partially	None	None	None	Immediate use
Ribeirinha	VII	Frame reinforced concrete	High	Good	1	Roof beams (pounding?)	Dislocated roof tiles and slight cracking in partition and external walls	Damage in external retaining walls	Use after moderate repairs
Espalhafatos	VII	Early reinforced concrete	High	Average	1	Damage at corners with separation between masonry and reinforced-concrete elements, damage at the column bases and cracks in external walls	Cracking in partition and external walls and floor settlement	Damage in external retaining walls	Use after extensive repairs
Salão	VII	Early reinforced concrete	High	Average	1	Damage at the columns	Cracking in partition and external walls and cracking in the connection between floors and walls	Damage in external retaining walls	Use after moderate repairs
Salão (kindergarten)	VII	Masonry wall	Medium	Average	1	External wall collapse	General damage	General damage	No use, demolition
Cedros	VI	Early reinforced concrete	High	Good	2	None	Cracking in partition and external walls	Cracking in external retaining walls	Immediate use
Cascalho	V-VI	Frame reinforced concrete	High	Good	1	Slight cracking in reinforced-concrete roof beams	Slight cracking in partition walls	Cracking in external retaining walls	Immediate use
Ribeira Funda	V	Masonry wall	High	Average	2	Extensive cracking in external walls	Cracking in partition walls	Damage in external retaining walls	No use, possible demolition
Praia do Norte	V	Frame reinforced concrete	High	Good	1	None	Slight cracking in partition walls	Damage in external retaining walls	Immediate use
Capelo	V	Early reinforced concrete	High	Good	1	None	None	None	Immediate use
Lombega	V-VI	Early reinforced concrete	High	Good	1	None	None	None	Immediate use
Castelo Branco (Carricja)	VI	Early reinforced concrete	High	Average	1	None	Cracking in partition walls, dislocated roof tiles and stucco and plaster crumbling	None	Use after moderate repairs
Castelo Branco (Farrobim)	VI	Early reinforced concrete	High	Good	1	None	None	None	Immediate use
Feteira (Travessa do Algar)	V	Frame and wall (7) reinforced concrete	High	Good	2, partially	None	None	Slight damage in external retaining walls	Immediate use
Feteira (Rua da Portela)	V	Early reinforced concrete	High	Good	1	None	None	Damage in electrical installations and in external retaining walls	Use after minor repairs
Horta (Pasteleiro)	V	Early reinforced concrete	High	Good	2, partially	None	None	None	Immediate use
Horta (Rua Consul Dabney)	V	Early reinforced concrete	High	Good	2, partially	None	None	None	Immediate use
Horta (Coronel Silva Leal)	V	Masonry wall	High	Average	2	Cracks in external and partition walls	Cracking in plaster ceilings	Damage in electrical installations	Use after moderate repairs
Horta (Gaiatos)	V	Frame and wall (7) reinforced concrete	High	Good	2	None	Cracking in plaster ceilings	None	Use after minor repairs

Figure 8.3. Severe cracking in internal partition walls at school in Espalhafatos



Figure 8.4. Damage in reinforced-concrete roof beams and in retaining walls at school in Ribeirinha



Figure 8.5. Cracking of stucco ceiling at Horta (Coronel Silva Leal) school



Figure 8.6. Dislocated roof tiles at Castelo Branco (Carreira) school



Figure 8.7. School in Espalhafatos: Separation between block masonry and reinforced-concrete elements



Figure 8.8. Collapse of external rubble masonry walls in kindergarten in Salão



in the "other" category was the collapse, cracking or overturning of earth-retaining walls, generally made of rubble masonry. This was caused by the fact that the buildings were generally constructed on relatively steep slopes. Dislocated tiles were also found on a number of educational buildings.

Interpretation of damage and conclusions

The extent and nature of damage in these educational buildings was strongly influenced by the structural solution. In recent reinforced-concrete structures, cracks were observed in structural elements, such as columns. Other side-effects were also noted, such as pounding and the development of short-column phenomenon resulting from partial, initial or damage-influenced restraint by adjacent non-structural masonry walls. In masonry structures, cracks of varying widths and extensions were observed in external and internal walls. Damage in early reinforced-concrete structures was similar, although less pronounced, than damage detected in masonry structures, with some signs of separation between the block masonry and reinforced-concrete discrete elements.

The extent of damage naturally depended on the site intensity and structural solution, but it was also found to be influenced by building quality and to a lesser extent the conservation condition. Given otherwise equal conditions, frame reinforced-concrete buildings performed better than early reinforced-concrete buildings, and these buildings performed better than masonry wall structures. Good building quality and conservation conditions were found to have a positive effect on building performance.

One of the most prevalent forms of damage

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Acknowledgements

The inspection results presented in this paper were compiled with the assistance of the National Civil Protection Service (SNPC) and the Azores Regional Civil Protection Service (SRPCA). The author also recognises the help and guidance of the Azores Regional Secretariat for Housing and Equipment. The processing of data was undertaken in co-operation with the ICIST/IST and the *Secretaria-Geral do Ministério da Educação* (General Secretariat of the Portuguese Education Ministry). The support of José Freire da Silva is gratefully acknowledged.