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KnowRISK

Know your city, Reduce seISmic risK through non-structural elements

Prevention and preparedness projects in civil protection and marine pollution. Prevention Priorities

Deliverable Report

Deliverable C2 – Identification of the most vulnerable non-structural components in the pilot study areas

Task C – Non-structural seismic risk reduction

Deliverable/Task Leader: EERC Revision:

Final

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Dissemination Level		
PU	Public	x
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

TABLE OF CONTENTS

LIST OF TABLES

Cap. 1.4

LIST OF FIGURES

1. DESCRIPTION OF THE DELIVERABLE

1.1 INTRODUCTION

The objective of the KnowRISK Action C.2 is to identify the most vulnerable non-structural components in the pilot study areas. In terms of methodology, this Action was achieved through analysis of patterns of non-structural damage occurred in recent earthquake events in KnowRISK case study areas.

1.2 THE ITALIAN CASE

1.2.1. Introduction

In Italy recent earthquakes have shown that damage caused by nonstructural failures can be relevant. Here we assess and discuss the sources of non-structural earthquake damage that might occur. We run a quantitative analysis in the Mt Etna volcano pilot area; we derived a qualitative assessment for most relevant situations of non-structural vulnerability throughout Italy.

In the Mt Etna volcano the analysis was carried out on non-structural damage occurred during recent earthquakes that caused moderate shaking. Data derived from the continuous activity of the local Civil Protection Agency (DPCR) that promptly verifies, in case of damaging events, the usability of damaged buildings. This information is reported in the forms for post-earthquake damage and safety assessment and short-term countermeasures (AeDES form - Agibilità e Danno nell'Emergenza Sismica, Baggio et al 2002).

The most common situation assessment of non-structural vulnerability relies on qualitative visual inspection review of non-structural damage caused by recent earthquakes in several localities throughout the country. They are representative for local building tradition and furnishing and privilege housing buildings, commercial facilities, and schools.

1.2.2. IDENTIFICATION OF THE MOST VULNERABLE NON-STRUCTURAL COMPONENTS IN THE MT. ETNA PILOT AREA

1.2.2.1 *Introduction*

We performe a retrospective analysis of the AeDES forms to extrapolate relationships between the non-structural damage (but also the structural one) and typology and related vulnerability of the considered building stock. This activity is carried out in cooperation with the technicians of DPCR (Dipartimento di Protezione Civile Regione siciliana) who have i) collected data during field surveys, ii) organised them in a database.

The list of the Etna earthquakes for which the AeDES electronic forms are available, is:

- 29/10/2002, 10:02 GMT, M 4.4, ep. area Bongiardo
- 29/10/2002, 16:39 GMT, M 4.0, ep. area Scillichenti
- 29/10/2002, 17:14 GMT, M 4.1, ep. area Milo

- 02/12/2002, 12:28 GMT, M 3.6, ep. area Macchia
- 20/04/2008, 07:47 GMT, M 3.2, ep. area Nicolosi

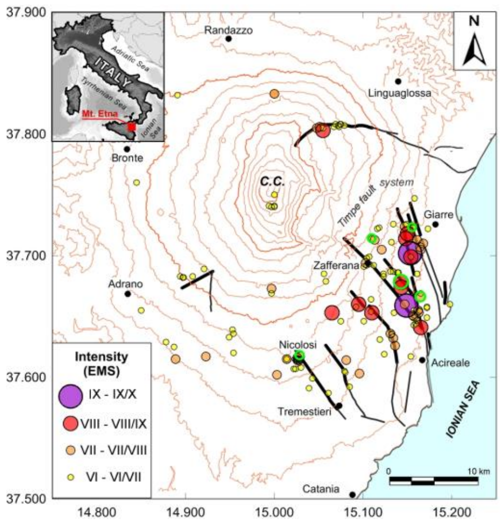


Figure 1. Location map of damaging earthquakes (I_0 ≥ VI EMS) occurring in the Etna area from 1600 to 2013 (data from CMTE Working Group, 2014). Solid lines indicate the main active faults (from Azzaro et al. 2012); C.C. central craters. The events selected for the non-structural analysis by the AeDES forms, are marked in green.

1.2.2.2 *The Italian AeDES form*

During post earthquake emergency, surveys on damaged construction stock are carried on in order to assess the usability of ordinary building and reduce the homeless hosted in temporary structures. All over the world, standardized inspection forms have been extensively used, since they provide a *check list* guiding the surveyor, improving judgement homogeneity in damage assessment and making computerisation and statistical treatment of the collected data easier.

In Italy, the AeDES survey form is the specific tool for damage assessment, short term countermeasures for damage limitation and evaluation of the post earthquake usability of ordinary buildings. The current first level release is an optimised form prepared by the National Group for the Defence against Earthquakes (GNDT) in 1996/7 (Baggio et al., 2002), for a faster insertion as compared to the former *vulnerability forms* (Benedetti e Petrini, 1984).

The AeDES form allows to assess damage and vulnerability in one single survey and gives a better estimate of seismic risk. Widening such a survey on a large amount of buildings standing in a defined area, gives an opportunity to collect data for a deep study concerning vulnerability and therefore building seismic loads.

The form is composed of nine sections in which predefined spaces and cells are to be filled by expert surveyors:

- Section 1 - Building **identifcation** (localizzazione, indirizzo, dati catastali);
- Section 2 – Building **description** (dati metrici, età di costruzione, destinazione d'uso, utilizzo);
- Section 3 – Structural **typology** (vertical and horizontal load bearing elements, roof typology, regularity in plan and elevation);
- Section 4 - **Damage** to **structural** elements and short-term countermeasures (estensione e livello del danno riportato a causa del sisma, oltre a quello eventualmente preesistente);
- Section 5 - **Damage** to **non-structural** elements and short-term countermeasures (estensione e livello del danno riportato a causa del sisma, oltre a quello eventualmente preesistente);
- Section 6 – Possible **external damage** due to adjoining constructions and short-term countermeasures;
- Section 7 - Possible **external damage** due to surrounding soil and foundations;
- Section 8 – **Usability** judgment (risultato dalla combinazione dei rischi strutturale, non strutturale, esterno e geotecnico);
- Section 9 – **Other** observations.

1.2.2.3 *Evaluation of buildings data surveyed into AeDES form*

Classification of building structural vulnerability

The classification of buildings vulnerability was carried on following the method proposed by Bernardini et al. (2008), which assigns a score to specific indicators supposed to be suitable variables for evaluating seismic resistance of a building.

The basic building vulnerability is defined for any construction types through an assigned specific value, index I_b, referring to every possible combinations between horizontal and vertical structure typologies, as described in AeDES form – Section 3.

The basic vulnerability indexes are reported in Table 1 (for masonry structures) and Table 2 (for reinforced concrete structures, also depending on the regularity of both plan/elevation and curtain wall disposition), while the next Table 3 gives some variations of index I_b according to possible mixed structures or different types of reinforcements/retrofittings:

Table 1 – Basic vulnerability I_b of masonry buildings (k=3)

AeDES references to floors/walls	**A (un-know)**	**B Irregular without ties**	**C Irregular with ties**	**D Regular without ties**	**E Regular with ties**	**F**
1 - unknow	57	65	60	55	50	With isolated columns add +5
2 - vaults without ties	67	75	70	65	60	
3 - vaults with ties	62	70	65	60	55	
4 - deformable slab	57	65	60	55	50	
5 - semi-rigid slab	52	60	55	50	45	
6 - rigid slab	47	55	50	45	40	

Table 2 – Basic vulnerability Ib of other typologies (k=1 and 2) depending on factors of regularity (1-plan or elevation; 2-infilled or curtain wall disposition)

AeDES references	**Factors of regularity**			
	1 irreg-2 irreg	1 irreg - 2 reg	1 reg- 2 irreg	1 reg – 2 reg
7 – R.C. frames	55	50	50	45
8 – R.C. walls	50	45	45	40
9 – Steel	45	40	40	35

Table 3 – Variation of basic vulnerability Ib of buildings with masonry mixed to others typologies (k=4) or reinforced.

AeDES references	**Variation of I_b**
G1 – R.C. storeys over masonry stroreys	0
G2 - masonry stroreys over R.C. storeys	+10
G3 – R.C. and masonry in the same stroreys	0
H1 – masonry with injections or plain plasters	-10
H2 – reinforced masonry or masonry with reinforced plasters	-20
H3 - masonry with others or not identified reinforces	-10

However, the final formula for the assessment of the overall vulnerability index I_v is the following:

$$I_v = I_b\,(k) + Delta\_i\,(k) * (i-1)/5 + Delta\_j\,(k) * (j-1)/5 + Classif\,(k) + \Sigma_r F_r$$

As you can see, other typological factors are considered to assign additional score taking into account the presence of some other inner elements and also outer site and environmental factors as:

- the roof typology (Section 3);
- the age of construction and the associated level of maintenance, added to the number of outside storeys (Section 2);
- the building position in the case it is aggregated in a group (Section 1);
- the possible pre-existing damage (Section 1);
- the safety of the site, deduced from the morphology and the possible instability of surrounding site and settlements (Section 7);
- the subjection of building to legal rules of seismic protection, as it was constructed after the classification of the municipality in a high seismic risk area.

Particularly, some of these factors (age of construction, number of storeys and structural aggregation) gave their contribute to the classification of the building vulnerability also when the assessment starts from the census data; instead, some other factors are coming only from AeDES forms. The former flow into the calculation of the coefficients **i** and **j** referring to the parameter **Delta_i(k)** and **Delta_j(k)**, the latter are represented by the variations of vulnerability $\mathbf{F_r}$, while **Classif (k)** specifies if the building was constructed when the Building Code was enforced.

The value of the above mentioned parameters for each structure typology is reported in Table 4, while the correlated coefficients i and j are defined as reported in Table 5.

Table 4 – Parameters of classification from AeDES

k (typology)	3 (masonry)	1 and 2 (other typologies)	4 (mixed or reinforced)	5 (unknow)
Delta_i(k)	-30	-25	-30	-27
Delta_j(k)	-15	-15	-15	-15
Classif (k)	-10	-20	-10	-15

Table 5 – Influence of age of construction and typological factors.

i	Range of age of construction	j	Typological factors	
			Aggregation	Number of storeys
1	< 1919	1	Extrem or corner	> 4
2	1919_1945	2	Extrem or corner	> 2 and < 5 or unknow
3	1946_1961 or unknow	3	Internal or isolated or unknow	> 4
4	1962_1971	4	Extrem or corner	1 or 2
5	1972_1981	5	Internal or isolated or unknow	> 2 and < 5 or unknow
6	1982_1991	6	Internal or isolated or unknow	1 or 2
7	1991_2001			
8	> 2001			

The typological factors included only into the AeDES forms, and not considered into the data taken from ISTAT census data, are listed in the table below (Table 6) together with the corresponding variation of the vulnerability index.

Table 6 – Typological factors F_r non considered in the ISTAT census data

AeDES refereces	**1 Heavy and thrusting**	**2 Heavy and not thrusting**	**3 Light and thrusting**	**4 Light and not thrusting**
ROOF	+5	0	0	-5
AeDES refereces	**Very serious**	**Serious**	**Light > 1/3**	**None or light < 1/3**
PRE-EXISTING	+40	+20	+10	0
AeDES refereces	**1 Top**	**2 Strong slope**	**3 Slight slope or unknow**	**4 Plain**
MOROHOLOGY OF THE SITE	+5	+5	0	0
AeDES refereces	**A Absent or unknow**	**B Created by earthquake**	**C Increased by earthquake**	**D Pre-existing**
SETTLEMENTS	0	+5	+5	+5

The EMS98 vulnerability class of the building is identified from the I_v index with the same criteria defined for classification based on ISTAT91, that is depending on the following ranges (Table 7):

Table 7 – Criterion of classification in EMS98 classes

EMS98 Classes	**A**	**B**	**C**	**D**	**E**	**F**
I_v (mean)	50< Iv	30<Iv<=50	10<Iv<=30	-10<Iv<=10	-30<Iv<= -10	Iv<= -30

For buildings built before 1991, lacking of damage and pre-existing settlement, the I_v index can be included between the following ranges:

Table 8- Vulnerability classes expected for each construction typology:

masonry buildings	k = 3	$-15 \leq I_v \leq 90$	Classes from A to D
reinforced concrete buildings	k = 1 e 2	$-25 \leq I_v \leq 65]$	Classes from A to E

Classification of the structural building damage

The damage class of a building is assigned according to the criteria proposed into the following reference study (Pinho, 2015, modified from S.A., 2014):

- assignment of a *synthetic damage for each of the five structural components* (vertical and horizontal structures, stairs, roof, infill-partition) by the determination of an univocal *damage level* which can vary between 0 and 5. The damage level depends on its degree and extension (Table 9), as it has been surveyed and reported in Section 4 of AeDES form.

Table 9 – Method for defining the level of synthetic damage for each structural component

Damage level d_i	**D1** **Light damage**	**D2-D3** **Moderate-heavy damage**	**D4-D5** **Very heavy damage**
0	None	None	None
1	> 1/3	None	None
2	Whatever	< 1/3	None
3	< 1/3	< 1/3	None
	< 2/3	< 1/3	< 1/3
4	Whatever	Whatever	< 2/3
5	< 1/3	Whatever	> 1/3

- the assessment of *global damage index of the structure* is done weighting the summation of *damage levels* respective on the five components of the structure, using different coefficients for masonry and reinforced concrete structures:

$$D_{TOT} = \Sigma_i \; d_i * p_i$$

with: $i=1\div5$; p_i is:

	Weights	
Component	**Masonry-Mixed**	**R.C. and others**
Vertical structures	0.6	0.5
Horizontal structures	0.2	0.1
Stairs	0.05	0.05
Roof	0.1	0.05
Partition walls	0.05	0.3

The final values of the global damage index are included between 0 and 5, according to the following approximations as it expressed in Table 10:

Table 10 - Criterion of classification in EMS98 damage classes.

EMS98 damage classes	**Range of D_{TOT}**
D0	$D_{TOT} = 0$
D1	$0 < D_{TOT} \leq 1.5$
D2	$1.5 < D_{TOT} \leq 2.5$
D3	$2.5 < D_{TOT} \leq 3.5$
D4	$3.5 < D_{TOT} \leq 4.5$
D5	$4.5 < D_{TOT} \leq 5$

1.2.2.4 *Data collections and first building damage analysis*

The collected data of the AeDES forms cover 23 municipalities of the Mt. Etna pilot area highlighted in figure 2 by the yellow shades.

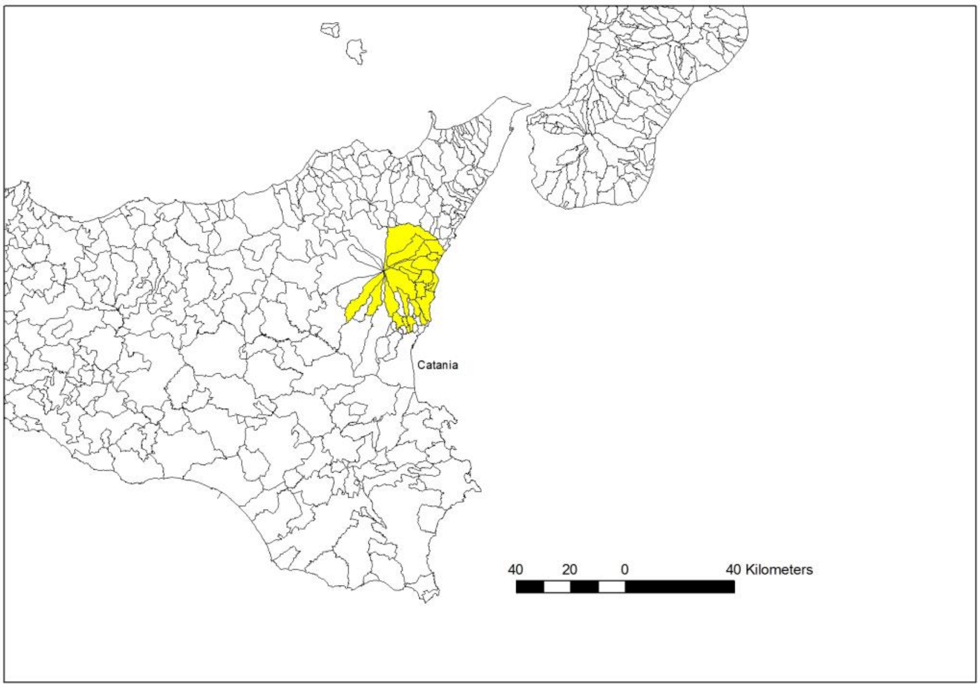


Figure 2. The map shows the distribution of the municipalities of the Mt. Etna pilot area where the AeDES forms are been collected after the seismic events with moderate level of shaking.

Typical damages to non-structural components are those concerning plasters, coatings, stuccos, false ceilings, infill panels, non-structural roof components, covering, eaves and parapets. Damages to the water, gas or electricity plants are also included.

In Section 5 of the AeDES survey form (figure 3), the presence of damage to non-structural component is registered together with the presence of existing short term countermeasures. Four rows of Section 5 concern the possible falling and separation of different components, while the last two rows concern damage to plants; for each of them, the presence of damage should be reported in the first column. For what concerns the existing short term countermeasures, the possible presence of several kinds of countermeasures for each type of damage reported, may be listed; if no short term countermeasures have been inserted before the inspection, the correspondent circular cell of the column None should be marked.

SECTION 5 Damage to non structural components and existing short term countermeasures

Damage	PRESENT	EXISTING SHORT TERM COUNTERMEASURES					
		None	Removal	Propping	Repair	No entry	Barriers or passage protection
	A	B	C	D	E	F	G
1 Falling of plaster, coverings, false-ceilings	○	○	☐	☐	☐	☐	☐
2 Falling of tiles, chimneys...	○	○	☐	☐	☐	☐	☐
3 Falling of eaves, parapets…	○	○	☐	☐	☐	☐	☐
4 Falling of other internal or external objects	○	○	☐	☐	☐	☐	☐
5 Damage to hydraulic or sewage systems	○	○			☐	☐	☐
6 Damage to electric or gas systems	○	○			☐	☐	☐

Figure 3. The section 5 of the AeDES form for collecting damage to non-structural components (from Baggio et al., 2007).

The aims of the work is to identify some of the most common situations of non-structural damage in the pilot area by means of analysing the data contained in the section 5 of the AeDES forms and trying to correlate the presence of non-structural damaged components to the classification of both building damage and structural vulnerability (evaluated by means of the procedures shown in the previous paragraphs).

As a first draft scheme of the damage, the following graph shows (figure 4.) the distribution of the global damage index of the surveyed structures included in the first release of AeDES forms database on the study area. The percentages describe the subdivision of this first set of 7331 AeDES forms for different buildings structural typologies (4460 of which are masonry and 2871 are R.C. buildings). As can be observed, in this first set of buildings there is the almost lack of structures with medium-heavy level of global structural damage (D2 and D3).

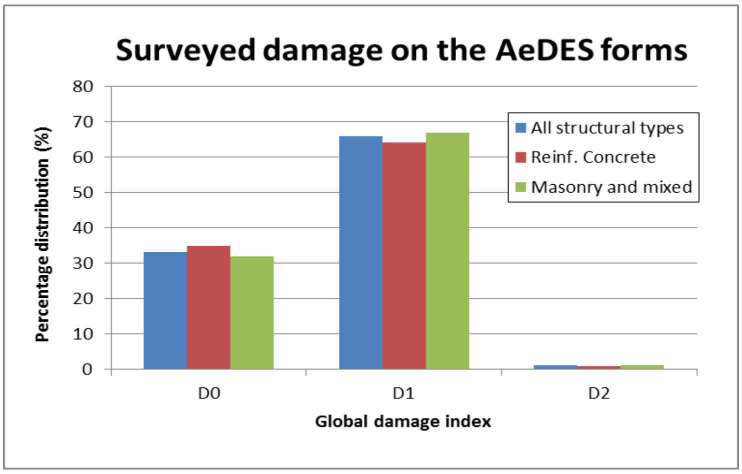


Figure 4. The distribution of collected data from the AeDES forms (in percentage) for each level of the global damage index of the structure for different building structural typologies.

1.2.3. RELEVANT SITUATIONS OF NON-STRUCTURAL VULNERABILITY DERIVED FROM RECENT EARTHQUAKES IN ITALY

We examined photos from the Mw5.9 2002 Molise, Mw4.6 2002 St Venerina, Mw6.3 2009 L'Aquila, Mw5.8 2012 Emilia and the Mw6.0 2016 Amatrice earthquakes. They all induced extensive damage, but here we higlight the non-structural elements only (Tab. 11)

The assessment of qualitative non-structural vulnerability situations in schools is also a matter of work within Task E and will be used to raise awareness in the populations on the needs to adopt low cost preventive measure. Here we highlights some relevant and common situations derived from a document of the Consiglio Superiore dei Lavori Pubblici in Italy (Intesa Rep. 7/CU 28/1/2009) published to allow assessment of non-structural vulerability in schools.

According to De Sortis et al., 2009 the most common non-structural elements are:

- Balconies (see table 11)
- roof tiles (see table 11)
- architectural ornaments (see table 11)

- heavy stucco soffit (see table 11)
- chimney
- ceiling moulding
- server and main service panels
- adhered veneer
- plaster (see tab 11)
- interior partitions (see table 11)
- Glass and window fixtures
- racks and bookshelves (see table 11)
- monitor
- light fixtures
- glass cabinets (see table 12)
- Lab appliances and chemicals (see table 12)
- signes
- parapets can get damaged because of inadequate bracing to the walls
- ornaments are common in door situation in countryside houses. However modern style furnished houses do often prefer shelves to cabinets. Heavy ornaments are normally placed even on top of high shelves.

Table 11 - Relevant situations of non-structural damage in Italy from recent earthquakes

Photo	Earthquake and reference	Non structural elements	Comments
 	2009 L'Aquila earthquake Sortis et al., 2009	Balconies and shutters	In masonry buildings stone slabs get damaged by vertical shaking at the joint between adjacent sabs and/or when anchorage is too wide or loose.
	2012 Amatrice sequence Azzaro, 2012	adhered veneer	It is quite common in Italy and suffer damage for non efficient acnhorage

	2009 L'Aquila earthquake Sortis et al., 2009	Roof tiles	Roof tiles tend to detach and slide as they are usually not anchored at the roof.
	2009 L'Aquila earthquake Sortis et al., 2009	epigraph stone	architectural ornamentation may fall due to vulnaerable anchorage
	2002 St Venerina (Catania)	infill-partition	
	Emilia 2012	heavy stucco ceiling	This is a situation that can occur both in cultural heritage buildings than in private housing

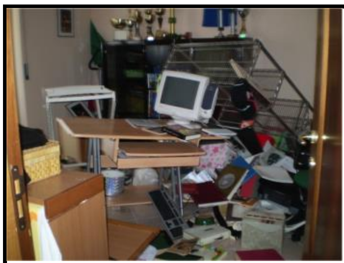
	2009 L'Aquila earthquake	Overloaded or not achored racks and bookshelves monitor	This is a common situation in private housing and bussiness
	2009 L'Aquila earthquake	Not anchored household appliances	This is a common situation in private housing
	2012 Amatrice sequence Azzaro, 2012	Interior partitions	
	Vulnerable interior parition and furnishing	Interior partition	A school after the 2002

Table 12 - Relevant situations of non-structural vulnerability in schools

Photo	Type of vulnerable situations		Comments
  	Vulnerable science labs	Chemicals, glasses and heavy tools	This are common situation in schools. Science laboratories might have glass cabinets for chemicals. Chemicals or other lab tools are also usually not ancored.

	Vulnerable ceiling	Ceiling plasters	Detachment of ceiling plasters
	Vulnerable ceiling	Weak anchorage of overloaded ceiling due to lights	Electical system overloading roof plaster slabs
	Vulnerable chimney	Weak and loose anchorage	Weak anchorage of tall chimney to the wall; upper slab just laying on top without any anchorage.
	Vulnerable ceiling in computer labs	Weak or loose slicee of ceiling moulding	Weak or loose anchorage in computer rooms

	Vulnerable interior parition and furnishing

1.3 THE ICELANDIC

1.3.1. Damage Data and AnalysisIntroduction

1.3.1.1 EERC DATA SET

The EERC data set was collected via site visits and telephone interview. It consists of digital data, photographs and completed questionnaires in paper form (see Figure 5). Most of the data is for single-family dwellings. The interviewees were usually bot the owners and occupants of the buildings. The interviews took place in the period 2000-2004 for the 2000 earthquakes, and in 2008 for the 2008 earthquake. The dataset for the 2000 is considerably larger and is separated for the 2000 17th June and the 21st June earthquakes.

The questionnaire is mainly divided into four parts:

a. How the interviews experience the earthquake
b. Movement of building content
c. Damages to the building, both structural and no-structural
d. Damages outside the building

At the time of the 2000 earthquakes, approximate 500 houses and 15,000 people lived in the two counties of study area, Árnessýsla and Rangárvallasýsla. It was estimated that the main impact area affected 2,4000 houses and 5,000 people. The survey covered 168 houses and 180 people (sometimes more than one person from the household was interviewed). The 168 houses were chosen to include a wide distribution in

- Geographical location
- Age
- Material and construction type

A few houses were included due to

- Closeness to epicentre or causative fault
- Buildings that housed the EERC strong motion accelerometers

Of the 168 buildings, 24 were studied intensively with data collection including on-site visits, while the data collection for the remaining 144 was performed by telephone surveys.

Figure5. EERC Damage Data Set

1.3.1.2 ANALYSIS

The analysis of the data involves extracting information about the building content (issue b) and non-structural damages (issue c) and relating these to the damages of the building itself (issue c).

The damage data, ground motion ranges (GM Range), both PGV and PGA and the five Damage States will be used to develop a DPM for South Iceland. An empty matrix is shown in Table 13.

Table 13 - Empty DPM for Non-structural elements vulnerability in study area

Nr	Damage State	GM Range 1	GM Range 2	GM Range 3	GM Range 4
1	None				
2	Minimal disruption				
3	Mild disruption				
4	Moderate-large Disruption				
5	Extensive disruption				

An example of photographic data from the EERC dataset is given in Figure 6. According to Damage State criteria, all photos fall under DS 5, extensive disruption. The photos are from the same building, a SFD in a high-ground motion region, but are from separate rooms in the house. The general opinion of the residents was that most of the damages occurred in the kitchen. An objective of the analysis is to determine if it is possible to determine different levels of disruptions for different rooms in the buildings.

(a)

(b)

(c)

(d)

(e)

Figure 6. Non-structural elements in the 2000 earthquake, (a) master bedroom, (b) children´s bedroom (c) hall (d) kitchen, (e) living room, and (f) washroom

1.3.2. Synopsis

This interim report outlines the method, methodology and key datasets that was used to complete Task C2. In what regards Iceland the next phase of Task C2 is to compile a database relevant to the objectives here from the EERC dataset.

The results of the compilation and analysis provided information about the most vulnerable Non-structural elements in South Iceland, although, any gaps in the data will be used to develop research agendas for future projects.

1.4 THE PORTUGUESE CASE

1.4.1. Introduction

A comprehensive seismic nonstructural survey and analysis of a building may require almost as much time as a structural analysis. The non-structural data collection is time-consuming because there are more items to observe and inventory, and they are spread throughout a building. Moreover, analysis of existing reports may be difficult as post-earthquake building surveys usually are not so much concerned with non-structural damage and performance of ornamental features and fixtures.

For the Portuguese case the information based on two earthquakes occurred in 1969 (affecting the mainland territory) and 1998 (Azores) will be analysed.

Although it is outside the Portuguese case study area, the information available from the 1998 Faial earthquake (Azores) will be analysed and compiled in order to identify some of the most common situations of non-structural vulnerability in Portugal.

The information gathered following these earthquakes shows that most of the economic loss comes from damage to non-structural components. There are two reasons for this. First, most of the total construction cost is due to non-structural components. The structure typically costs about 20% to 30% of the whole building cost and the rest is due to non-structural components and contents (Taghavi and Miranda, 2003). Also, damage to non-structural elements is more frequent compared to damage to structural elements.

1.4.2. IDENTIFICATION OF THE MOST VULNERABLE NON-STRUCTURAL COMPONENTS IN THE PORTUGUESE PILOT AREA

1.4.2.1 *The 1969 Earthquake*

On February 28th, 1969 an earthquake (Mw8.0) struck western Portugal and Morocco with epicentre 230 km SW of Lisbon in the main fracture zone, Azores - Gibraltar. The event had 30 sec duration, the peak ground acceleration in Lisbon was 0.05 g and a small tsunami was generated (Miranda et al, 2014; Oliveira, 1982). Intensities VI-VII (MM56) were felt in Libon (Figure 7).

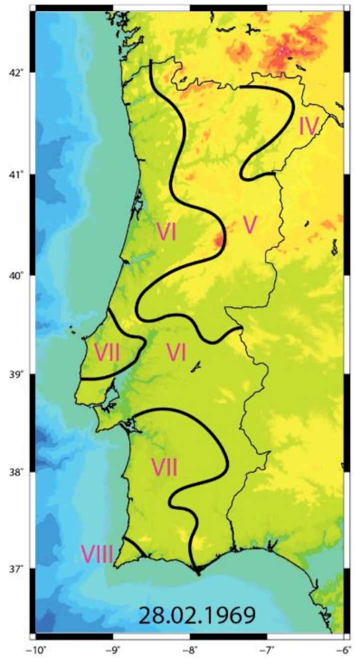


Figure 7. Isosseismal map for the 1969 earthquake (Adapted from Moreira, 1991)

The resulting damage killed thirteen people (11 in Morocco and 2 in Portugal). Damage to local buildings was "moderate", according to the United States Geological Survey, "in Lisbon, numerous cars were damaged by falling chimneys, balconies, and walls and many people were injured by falling debris. Several old masonry buildings collapsed in surrounding towns and Algarve".

Table 14 reports the damage inflicted during the 1969 earthquake according to the Fire Brigade Headquarter's files, reported during the first month after the event (Oliveira, 1982). In the following months an average of 70 cases of damage/month were reported. Ten years later people still call reporting damage due to the earthquake. 1.8% of the total received calls were false.

Table 14 - Damage inflicted in Lisbon, 1969 earthquake.

Type of damage	**Number of reported cases**	**Zones of higher damage**
Broken windows and out-of-frame doors	19	
Water infiltration due to minor cracking*	884	Anjos, Alameda
Collapse of masonry chimneys	985	Baixa, Estrela, Anjos
Fall of appendages	56	
Cracks and spalling of plasters, ceilings; damage in roofs and landslides	189	Alameda, Anjos
Moderate structural damage, in some cases requiring evacuation.	316	Alfama, Anjos, Estrela
Total		

*Heavy rains poured in Lisbon during the days that followed the earthquake causing additional soil and structural instabilities.

Table 15 shows the damages in Lisbon regarding the parish information at the time of the earthquake.

It is important to note that Alvalade (KnowRISK pilot study area) parish was planned in the 30's (Avenida de Roma) (as consequence of Lisbon's expansion towards the plateau on the North side of the city) and it was partially built in the 50's. After the 1950s masonry was no longer used as a structural material in the construction of buildings in Lisbon, being limited to the construction of single family houses on the rest of the country (Simões et al., 2012). In 1969, Alvalade was a new neighbourhood with recent construction and as expected there was no major structural damages, just some non-structural damages ocurred, as shown in Table 15.

Table 15 – Relevant damages observed in each Lisbon parish.

LISBON PARISHES	Broken windows and out-of-frame doors	Water infiltration / minor cracking	Collapse masonry chimneys	Fall of appendages	Cracks, spalling of plasters, ceilings; damage in roofs and landslides	Moderate structural damage, in some cases requiring evacuation	TOTAL
S. FRANCISCO XAVIER		1	1				**2**
S. JOÃO DEUS	1	2	3			2	**8**
S. VICENTE FORA		24	20		2	9	**55**
SÉ		12	19	1		5	**37**
S. JOSÉ		19	25	2	8	9	**63**
SANTOS-O-VELHO		47	63	2	6	18	**136**
S. NICOLAU		22	47	2	9	2	**82**
S. JUSTA	2	24	27	5	4	11	**73**
S. MAMEDE		18	24		2	5	**49**
S. ISABEL		7	4		1	1	**13**
S. CONDESTÁVEL		24	25	1	6	9	**65**
S. DOMING. BENFICA		12	6		2		**20**
N.S.PENA	2	30	22	2	5	10	**71**
S. JORGE ARROIOS	1	79	73	4	15	10	**182**
ALVALADE		4	5			2	**11**
CHARNECA	1	2					**3**
N.S.GRAÇA		51	42		7	8	**108**
S. PAULO	1	21	45	3	4	7	**81**
S. ENGRACIA		8	8	1	2	6	**25**
S. SEBAST. PEDR.		12	11		1	4	**28**
BEATO		18	9		6	7	**40**
ALTO DE PINA	2	5	4				**11**

S. ESTEVÃO	1	15	14	2	2	9	**43**
N.S.MÁRTIRES		4	12	4	3	1	**24**
S. TIAGO		10	6		1	2	**19**
CAMPOLIDE		12	6		1	10	**29**
ALCÂNTARA		16	21	3	7	5	**52**
PENHA DE FRANÇA		37	35	1	9	9	**91**
CASTELO	1	8	6		1	7	**23**
SOCORRO		22	15	1	5	3	**46**
S. JOÃO	1	26	27	1	10	4	**69**
S. MARIA OLIVAIS		11	1			2	**14**
LUMIAR		8	3			2	**13**
CORAÇÃO DE JESUS		18	17	6	5	3	**49**
S. MIGUEL		28	10		4	14	**56**
ANJOS	2	30	58	2	18	18	**128**
MERCÊS		20	41		6	10	**77**
N.S.FÁTIMA	3	22	47		3	14	**89**
AJUDA		16	6	2	4	9	**37**
AMEIXOEIRA		1	1	1		1	**4**
ENCARNAÇÃO		21	31	2	9	7	**70**
C.GRANDE		7	3			3	**13**
S.JOÃO BRITO		2	4		2	4	**12**
MARVILA	1	8	8		4	14	**35**
SACRAMENTO		10	9	2	2	1	**24**
S.CATARINA		35	42	3	2	5	**87**
MADALENA		7	6		1		**14**
LAPA		21	34		3	14	**72**
CARNIDE		4				1	**5**
BENFICA		11	7		1	5	**24**
PRAZERES		6	11	1	2	5	**25**
S. CRISTOVÃO S. LOURENÇO		6	16	1	3	7	**33**
S. MARIA BELÉM		9	6		1	2	**18**

TOTALS	**19**	**893**	**986**	**55**	**189**	**316**	**2458**

Figure 8 shows the damage distribution in Lisbon downtown according with Table 15.

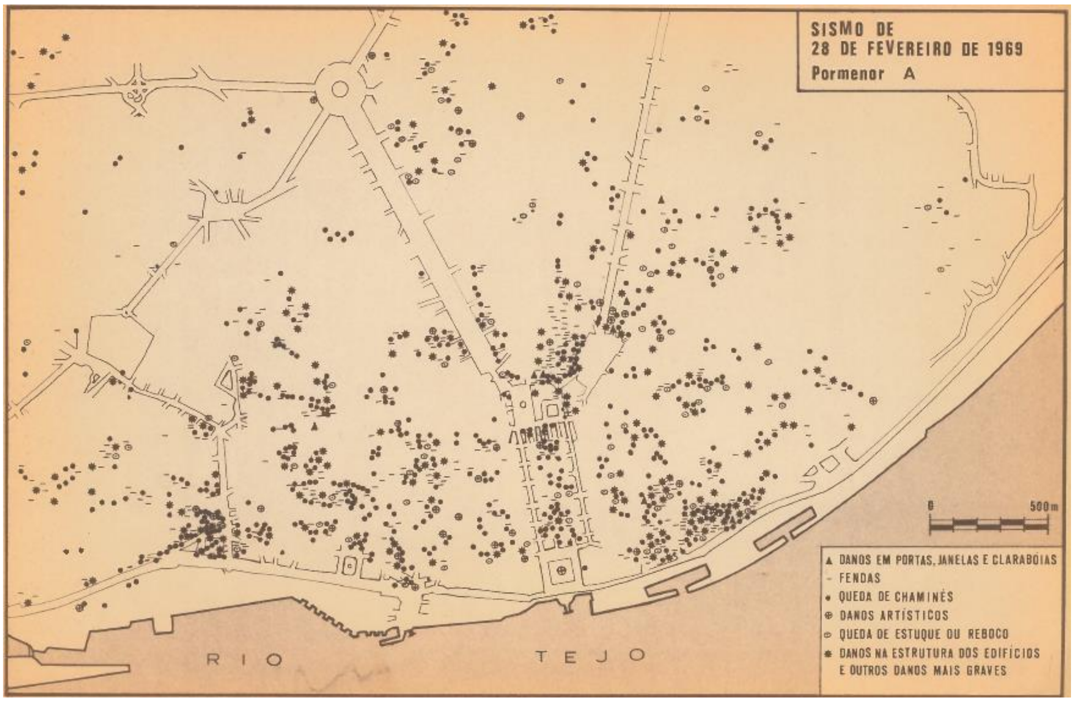


Figure 8. Damage distribution in downtown Lisbon

1.4.2.2 ***The 1998 Azores earthquake***

The earthquake that struck Faial, Pico and S. Jorge in 1998 (Mw 6.2) has allowed the collection of an unprecedented quantity of good quality data about damage in constructions.

A post-earthquake survey named "Auto de Vistoria" was carried out in 1998 and further updated in 2007 (Neves et al., 2008). A total of 3909 buildings damaged were analysed case by case (Ferreira, 2008) and it was possible to establish a damage classification using the European Macroseismic Scale (EMS-98).

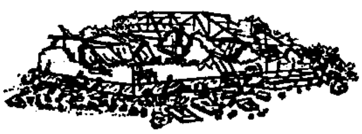
The knowledge about typical damage types on buildings is necessary to interpret and classify the observed damaged buildings. The interpretation of building survey data is a very complex subject and must be related to the reason for the survey - and general the reasons are: a) to identify buildings that can be reinstated or have to be demolished, b) to define economic losses to building stock.

The AeDES field manual (a tool for damage assessment, short term countermeasures for damage limitation and evaluation of the post earthquake usability of ordinary buildings, Baggio et al., 2007) and all the information contained on "European Macroseismic Scale" (Grünthal l et al., 1998) were used as guidelines to the EMS-98 classification.

Under the KnowRISK project several photos from 1998 earthquake were analysed in detail in order to collect and identify common damage to non-structural components and contents. According to EMS-98 (table 15), damage in buildings is classified from D1 (slight damage) to D5 (collapse). It is important to notice that the slight structural damage D1 is associated to low structural risk (even if a severe non-structural damage cannot be excluded), while the damage D4-D5 is in any case associated to high structural risk and both cases are easy to identify. The intermediate damage level D2-D3 includes a variety of situations which, depending on damage grade and extension, may lead to different conclusions on structural and non-structural risk: its interpretation is hence more difficult and complex.

The following pages therefore describe how the non-structural elements were analysed and interpreted using the numerous photos of damaged buildings, the EMS-98 (Tables 16 and 17) and AeDES (Figure 9) guidelines.

Table 16 – Classification of damage on structural and non-structural elements to masonry buildings

Damage grade (D)	
	D1 – Negligible to slight damage No structural damage, slight non-structural damage Crack width ≤1mm without material expulsion (type 1 and 5). Limited separations or slight dislocations (≤ 1 mm) between parts of structures, for example between walls and floors or between walls and stairs or between orthogonal walls (type 11). Fall of small pieces of plaster only. Fall of loose stones/tiles from upper parts of buildings in very few cases.
	D2 – Moderate damage Slight structural damage, moderate non-structural damage. Cracks in many walls (~1cm) close to the openings (type 1 and 5 from Figure 7) also with expulsion of material. Some separations (> 1 mm) between floors and/or stairs and walls and between orthogonal walls, some partial collapses in the secondary beams of the floors. Fall of fairly large pieces of plaster. Partial collapse of chimneys.
	D3 – Severe damage Moderate structural damage, heavy non-structural damage. Large and extensive cracks in most walls (1.5 cm) close to the openings (type 1 and 5, Figure 7) also with expulsion of material. . Significant separations between floors and/or stairs and walls and between orthogonal walls, some partial collapses in the secondary beams Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls).
	D4 – Very heavy damage Heavy structural damage, very heavy non-structural damage. Serious failure of walls. Partial structural failure of roofs and floors.
	D5 – Destruction Very heavy structural damage Total or near total collapse.

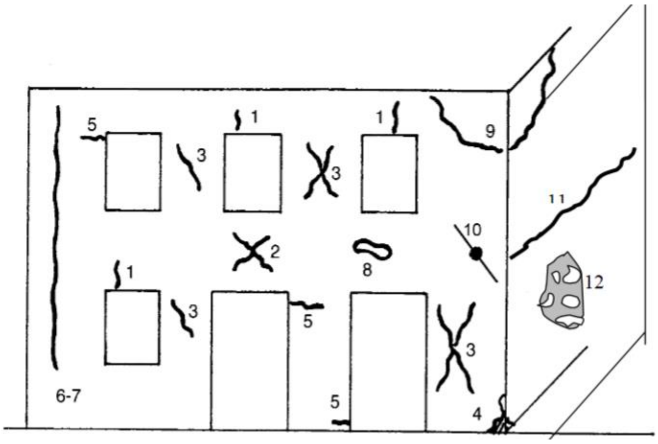
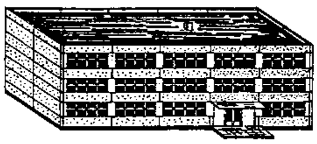
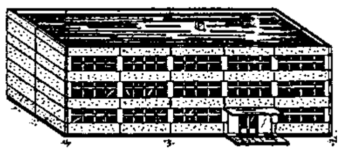
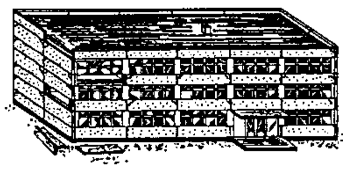
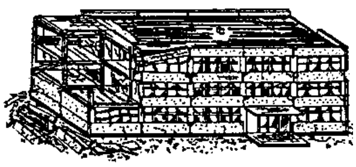


Figure 9. Scheme for cracks in masonry (AeDES. Baggio et al., 2007)

1: nearly vertical cracks on the lintelsbetween opening
2: diagonal cracks in the spandrel beams (window parapets, lintels)
3: diagonal cracks in vertical elements (masonry piers);
4: local crushing of masonry with or without material expulsion;
5: nearly horizontal cracks at the top and/or at the foot of masonry piers;
6: nearly vertical cracks at walls intersections;
7: same as 6 but with through cracks;
8: material expulsion at the beam supports due to pounding;
9: formation of a displaced wedge at the intersection of two orthogonal walls;
10: failure of tie rods or bond slippage;
11: horizontal cracks at the floor level or at the attic level;
12: separation of one of the wythes of a double-wythe wall.

Table 17 – Classification of damage on structural and non-structural elements to reinforced concrete buildings

Damage grade (D)	
	D1 – Negligible to slight damage No structural damage, slight non-structural damage . Slight cracks in the beams (up to 1 mm), widespread, but not vertical. Fine cracks in plaster over frame members or in walls at the base. Cracks (< 0.5 mm) in columns or in partitions.
	D2 – Moderate damage Slight structural damage, moderate non-structural damage Cracks in columns and beams of frames and in structural walls with expulsion of material. Cracks (> 2 mm) in partition and infill walls due to the separation from the structure, diagonal cracks up to few mm. Fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.
	D3 – Severe damage Moderate structural damage, heavy non-structural damage. Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of concrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels.
	D4 – Very heavy damage Heavy structural damage, very heavy non-structural damage. Large cracks in structural elements with compression failure of Concrete and fracture of rebar; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor..
	D5 – Destruction Collapse of ground floor or parts (e. g. wings) of buildings.

Several examples illustrating the classification of building damage for masonry and reinforced concrete buildings in Azores are presented in Table 18.

Table 18 – Examples of damage grade classification to masonry and reinforced concrete buildings - Azores

Level	Masonry	Reinforced concrete
D1	 Slight damage – cracks of width ≤ 1 mm.	 Slight damage – Slight cracks (≤ 2 mm).
D2	 Slight structural damage. Fallen of plaster.	 Separation between floor and wall.
D3		

	 Falling of tiles. Large and extensive cracks in the exterior walls.	
D4	 Partial failure of wall.	
D5	 Collapse of masonry walls.	

The assessment of the damage suffered with regard to housing, revealed that 88% of the Faial houses contained in the database "Base Integrada", have suffered some kind of damage D1 to D5. Pico presents a total of 67% dwellings with damage (Figure 10).

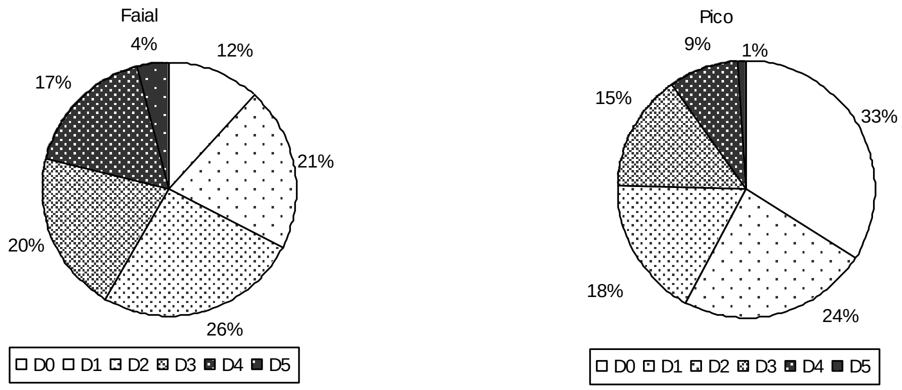


Figure 10. Faial and Pico grade of damage distribution ("Base Integrada").

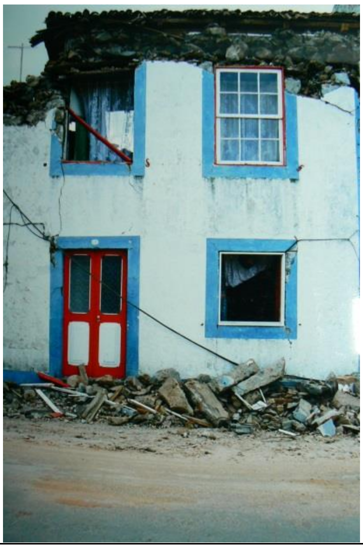
As illustrated in Figure 10, more than 40% of the buildings suffered non-structural damages (D2-D3).

Finally, by looking at what has happened to components in the 1998 earthquake, we can figure out the most common types of damage to components (Table 19) and use this information in future works.

Table 19 – Typical damage to non-structural components - Azores

	Miss of latches to prevent cabinet doors from opening

	Fall of pieces of plaster.
 	Damage grade 3 Unreinforced masonry chimneys are extremely vulnerable to earthquake damage. Chimneys may crack, spall, separate from the structure, or collapse. They may fall through the roof structure and injure occupants or fall to the ground.

	damage to exterior walls around windows
	Non anchored masonry veneer Falling masonry walls may injure people and block pedestrian walkways, driveways, streets and access for emergency vehicles during an emergency.

	Roof tiles detached
	Failure of walls and contents.

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Baggio C., Bernardini A., Colozza R., Corazza L., Della Bella M., Di Pasquale G., Dolce M., Goretti A., Martinelli A., Orsini G., Papa F., Zuccaro G. [2007] *Field Manual for post-earthquake damage and safety assessment and short term countermeasures (AeDES)*, Editors: Pinto A.V., Taucer F., European Commission - Joint Research Centre, Institute for the Protection and Security of the Citizen - Scientific and Technical Reports, 100 pp.

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1.5 APPENDICES

AEDES FORM

Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

CONFERENZA DELLE REGIONI E DELLE PROVINCE AUTONOME

SCHEDA DI 1° LIVELLO DI RILEVAMENTO DANNO, PRONTO INTERVENTO E AGIBILITÀ PER EDIFICI ORDINARI NELL'EMERGENZA POST-SISMICA
(AeDES 06/2008)

Codice Richiesta

SEZIONE 1 Identificazione edificio

Provincia:
Comune:
Frazione/Località: (denominazione Istat)

1 ❍ via
2 ❍ corso Num. Civico
3 ❍ vicolo
4 ❍ piazza
5 ❍ altro (Indicare: contrada, località, traversa, salita, etc.)

Coordinate geografiche (ED50 – UTM fuso 32-33) E N *Fuso*

IDENTIFICATIVO SOPRALLUOGO giorno mese anno
Squadra Scheda n. Data

IDENTIFICATIVO EDIFICIO
Istat Reg. Istat Prov. Istat Comune N° aggregato N° edificio

Cod. di Località Istat Tipo carta
Sez. di censimento Istat N° carta

Dati Catastali Foglio Allegato
Particelle

Posizione edificio 1 ❍ Isolato 2 ❍ Interno 3 ❍ D'estremità 4 ❍ D'angolo

Denominazione edificio o proprietario

Codice Uso S

Fotocopia dell'aggregato strutturale con identificazione dell'edificio

SEZIONE 2 Descrizione edificio

Dati metrici				*Età*	*Uso - esposizione*			
N° Piani totali con interrati	*Altezza media di piano* [m]	*Superficie media di piano* [m²]		*Costruzione e ristrutturaz.* [max 2]	*Uso*	*N° unità d'uso*	*Utilizzazione*	*Occupanti*
					A ❑ Abitativo			100 10 1
								0 0 0
❍1 ❍9	1 ❍ ≤ 2.50	A ❍ ≤ 50	I ❍ 400 ÷500	1 ❑ ≤ 1919	B ❑ Produttivo		A ❍ > 65%	1 1 1
❍2 ❍10	2 ❍ 2.50÷3.50	B ❍ 50 ÷ 70	L ❍ 500 ÷650	2 ❑ 19 ÷ 45	C ❑ Commercio		B ❍ 30÷65%	2 2 2
❍3 ❍11	3 ❍ 3.50÷5.0	C ❍ 70 ÷ 100	M ❍ 650 ÷900	3 ❑ 46 ÷ 61	D ❑ Uffici		C ❍ < 30%	3 3 3
❍4 ❍12	4 ❍ > 5.0	D ❍ 100 ÷ 130	N ❍ 900 ÷1200	4 ❑ 62 ÷ 71	E ❑ Serv. Pub.		D ❍ Non utilizz.	4 4 4
❍5 ❍>12		E ❍ 130 ÷ 170	O ❍ 1200 ÷1600	5 ❑ 72 ÷ 81	F ❑ Deposito		E ❍ In costruz.	5 5 5
❍6	*Piani interrati*	F ❍ 170 ÷ 230	P ❍ 1600 ÷2200	6 ❑ 82 ÷ 91	G ❑ Strategico		F ❍ Non finito	6 6 6
❍7	A ❍ 0 C ❍ 2	G ❍ 230 ÷ 300	Q ❍ 2200 ÷3000	7 ❑ 92 ÷ 01	H ❑ Turis-ricet.		G ❍ Abbandon.	7 7 7
❍8	B ❍ 1 D ❍ ≥3	H ❍ 300÷ 400	R ❍ > 3000	8 ❑ ≥ 2002		*Proprietà*	A ❍ Pubblica B ❍ Privata	8 8 8 / 9 9 9

Istat Provincia |__|__|__|	Istat Comune |__|__|__|	Rilevatore |__|__|	N° scheda |__|__|__|__|__|	Data |__|__|__|__|__|__|

SEZIONE 3 Tipologia (multiscelta; per gli edifici in muratura indicare al massimo 2 tipi di combinazioni strutture verticali-solai)

Strutture verticali / Strutture orizzontali	Non identificate	Strutture in muratura: A tessitura irregolare e di cattiva qualità (Pietrame non squadrato, ciottoli,..) – Senza catene o cordoli	Con catene o cordoli	A tessitura regolare e di buona qualità (Blocchi; mattoni; pietra squadrata,..) – Senza catene o cordoli	Con catene o cordoli	Pilastri isolati	Mista	Rinforzata
	A	B	C	D	E	F	G	H
1 Non Identificate	○	□	□	□	□	SI	□	□
2 Volte senza catene	□	□	□	□	□	○	G1	H1
3 Volte con catene	□	□	□	□	□		□	□
4 Travi con soletta **deformabile** (travi in legno con semplice tavolato, travi e voltine,...)	□	□	□	□	□	NO	G2	H2
5 Travi con soletta **semirigida** (travi in legno con doppio tavolato, travi e tavelloni,...)	□	□	□	□	□	○	□	□
6 Travi con soletta **rigida** (solai di c.a., travi ben collegate a solette di c.a,...)	□	□	□	□	□		G3	H3

Altre strutture	
Telai in c.a.	□
Pareti in c. a.	□
Telai in acciaio	□

REGOLARITA'	Non regolare A	Regolare B
1 Forma pianta ed elevazione	○	○
2 Disposizione tamponature	○	○

Copertura

1 ○ Spingente pesante
2 ○ Non spingente pesante
3 ○ Spingente leggera
4 ○ Non spingente leggera

SEZIONE 4 Danni ad ELEMENTI STRUTTURALI e provvedimenti di pronto intervento (P.I.) eseguiti

Livello - estensione / Componente strutturale - Danno preesistente	DANNO (1) D4-D5 Gravissimo > 2/3	1/3 - 2/3	< 1/3	D2-D3 Medio grave > 2/3	1/3 - 2/3	< 1/3	D1 Leggero > 2/3	1/3 - 2/3	< 1/3	Nullo	PROVEDIMENTI DI P.I. ESEGUITI: Nessuno	Demolizioni	Cerchiature e/o tiranti	Riparazione	Puntelli	Transenne e protezione passaggi
	A	B	C	D	E	F	G	H	I	L	A	B	C	D	E	F
1 Strutture verticali	□	□	□	□	□	□	□	□	□	○	○	□	□	□	□	□
2 Solai	□	□	□	□	□	□	□	□	□	○	○	□	□	□	□	□
3 Scale	□	□	□	□	□	□	□	□	□	○	○	□	□	□	□	□
4 Copertura	□	□	□	□	□	□	□	□	□	○	○	□	□	□	□	□
5 Tamponature-tramezzi	□	□	□	□	□	□	□	□	□	○	○	□		□	□	□
6 Danno preesistente	□	□	□	□	□	□	□	□	□	○						

(1) - Di ogni livello di danno indicare l'estensione solo se esso è presente. Se l'oggetto indicato nella riga non è danneggiato campire **Nullo**.

SEZIONE 5 Danni ad ELEMENTI NON STRUTTURALI e provvedimenti di pronto intervento eseguiti

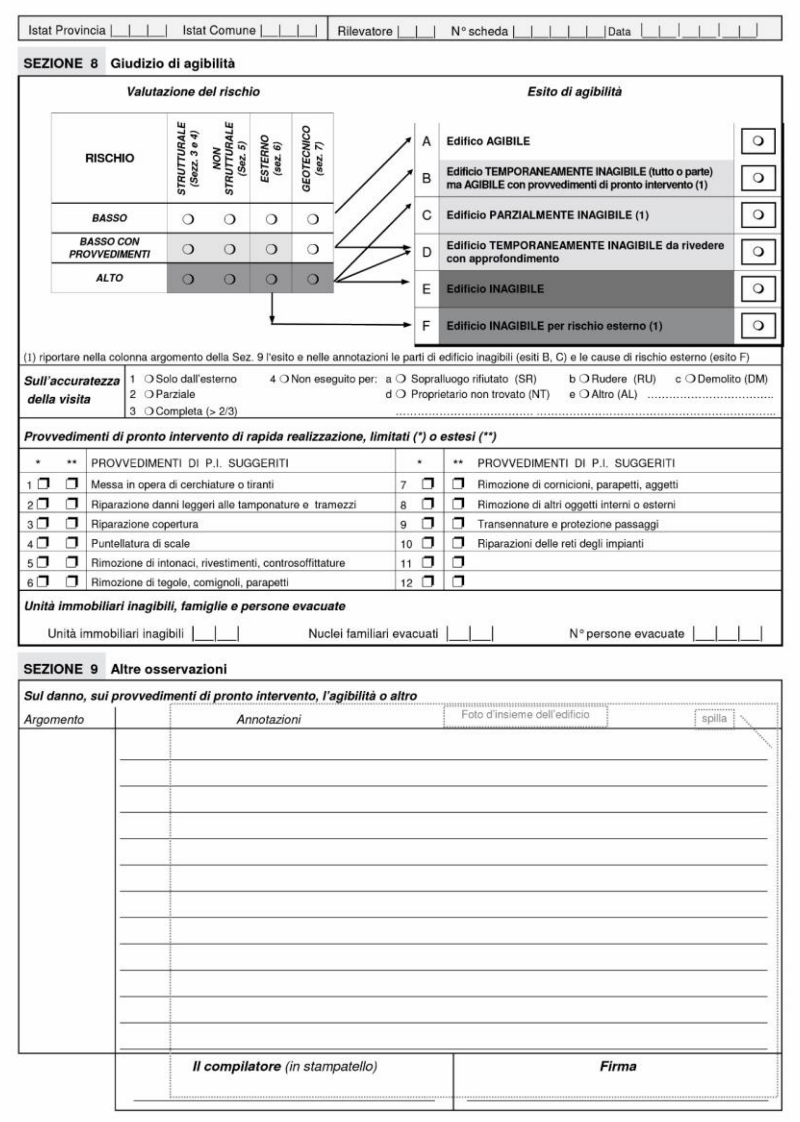
Tipo di danno	PRESENZA DANNO	PROVVEDIMENTI DI P.I. ESEGUITI: Nessuno	Rimozione	Puntelli	Riparazione	Divieto di acccesso	Transenne e protezione passaggi
	A	B	C	D	E	F	G
1 Distacco intonaci, rivestimenti, controsoffitti...	○	○	□	□	□	□	□
2 Caduta tegole, comignoli...	○	○	□	□	□	□	□
3 Caduta cornicioni, parapetti...	○	○	□	□	□	□	□
4 Caduta altri oggetti interni o esterni	○	○	□	□	□	□	□
5 Danno alla rete idrica, fognaria o termoidraulica	○	○			□	□	□
6 Danno alla rete elettrica o del gas	○	○			□	□	□

SEZIONE 6 Pericolo ESTERNO indotto da altre costruzioni e provvedimenti di p.i. eseguiti

Causa potenziale	PERICOLO SU: Edificio	Via d'accesso	Vie interne	PROVVEDIM. DI P.I. ESEGUITI: Divieto di accesso	Transenne e protez. passaggi
	A	B	C	D	E
1 Crolli o cadute da altre costruzioni	□	□	□	□	□
2 Rottura di reti di distribuzione	□	□	□	□	□

SEZIONE 7 Terreno e fondazioni

MORFOLOGIA DEL SITO	DISSESTI (in atto o temibili): □ Versanti incombenti □ Terreno di fondazione
1 ○ Cresta 2 ○ Pendio forte 3 ○ Pendio leggero 4 ○ Pianura	A ○ Assenti B ○ Generati dal sisma C ○ Acuiti dal sisma D ○ Preesistenti



Istat Provincia |__|__|__| Istat Comune |__|__|__| Rilevatore |__|__| N° scheda |__|__|__|__|__| Data |__|__|__|__|__|__|

SEZIONE 8 Giudizio di agibilità

Valutazione del rischio

RISCHIO	STRUTTURALE (Sezz. 3 e 4)	NON STRUTTURALE (Sez. 5)	ESTERNO (sez. 6)	GEOTECNICO (sez. 7)
BASSO	❍	❍	❍	❍
BASSO CON PROVVEDIMENTI	❍	❍	❍	❍
ALTO	❍	❍	❍	❍

Esito di agibilità

A	Edifico AGIBILE	❍
B	Edificio TEMPORANEAMENTE INAGIBILE (tutto o parte) ma AGIBILE con provvedimenti di pronto intervento (1)	❍
C	Edificio PARZIALMENTE INAGIBILE (1)	❍
D	Edificio TEMPORANEAMENTE INAGIBILE da rivedere con approfondimento	❍
E	Edificio INAGIBILE	❍
F	Edificio INAGIBILE per rischio esterno (1)	❍

(1) riportare nella colonna argomento della Sez. 9 l'esito e nelle annotazioni le parti di edificio inagibili (esiti B, C) e le cause di rischio esterno (esito F)

Sull'accuratezza della visita
1 ❍ Solo dall'esterno 4 ❍ Non eseguito per: a ❍ Sopralluogo rifiutato (SR) b ❍ Rudere (RU) c ❍ Demolito (DM)
2 ❍ Parziale d ❍ Proprietario non trovato (NT) e ❍ Altro (AL) ....
3 ❍ Completa (> 2/3)

Provvedimenti di pronto intervento di rapida realizzazione, limitati (*) o estesi (**)

*	**	PROVVEDIMENTI DI P.I. SUGGERITI	*	**	PROVVEDIMENTI DI P.I. SUGGERITI
1 ❒	❒	Messa in opera di cerchiature o tiranti	7 ❒	❒	Rimozione di cornicioni, parapetti, aggetti
2 ❒	❒	Riparazione danni leggeri alle tamponature e tramezzi	8 ❒	❒	Rimozione di altri oggetti interni o esterni
3 ❒	❒	Riparazione copertura	9 ❒	❒	Transennature e protezione passaggi
4 ❒	❒	Puntellatura di scale	10 ❒	❒	Riparazioni delle reti degli impianti
5 ❒	❒	Rimozione di intonaci, rivestimenti, controsoffittature	11 ❒	❒	
6 ❒	❒	Rimozione di tegole, comignoli, parapetti	12 ❒	❒	

Unità immobiliari inagibili, famiglie e persone evacuate

Unità immobiliari inagibili |__|__| Nuclei familiari evacuati |__|__| N° persone evacuate |__|__|__|

SEZIONE 9 Altre osservazioni

Sul danno, sui provvedimenti di pronto intervento, l'agibilità o altro

Argomento	*Annotazioni*
	Foto d'insieme dell'edificio spilla

Il compilatore** (in stampatello)* ***Firma