Technical Commission on Seismic Microzonation
(article 5, comma 7 of OPCM 13 November 2010, n. 3907)

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

SEISMIC MICROZONATION

LAND USE GUIDELINES FOR AREAS AFFECTED BY LIQUEFACTION (LQ)

Version 1.0

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Land Use Guidelines for Areas Affected by Liquefaction (LQ)
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PREFACE

The present document represents a modification to and integration of the "Guidelines for Seismic Microzonation" (GSM, 2008; Gruppo di Lavoro MS, 2008; English version: SM Working Group, 2015), specifically the section dedicated to phenomena of liquefaction. The integrations also take into account the experience of the earthquake that struck the area of Po Valley and Reggio Emilia in May 2012 and the studies produced in its wake.

The primary objective of these guidelines is the definition of general criteria and operative procedures, in coordination with State, Regional and Local Entities, to:

- gather accurate information about the risks induced by the presence of terrains susceptible to liquefaction;
- manage risk in undeveloped areas (with or with no plans for development);
- mitigate risk in developed areas.

Regarding the data to be used, according to the GSM (2008), the Map of Seismically Homogenous Microzones (SHM Map; Level 1) can be prepared using pre-existing information, when sufficient. In the majority of cases, pre-existing or so-called "poor" information (referred to here as "minimum informative elements"), consists of basic data such as the description of lithological units based on visual inspections, water table levels surveyed during perforations, etc. For this reason, to identify and define the susceptibility to liquefaction in studies related to the SHM Map (Level 1), methods are proposed that make use of immediately available information – gathered *in situ* – or present in literature or public databases.

On the contrary, in the event that a lack of pre-existing or quantitatively and qualitatively insufficient may lead to an excessive proliferation of areas to be investigated and when information is excessively scarce it would be opportune to gather new information during the early phases of any study.

The realisation of the Map of Seismic Microzonation (SM Map, Level 3) requires, instead, the completion of specific investigations and in-depth studies necessary to define soil characteristics.

Regarding methods of data processing, these Guidelines, that being shared with the Regions constitute an integration of the GSM (2008), must necessarily be based on available technical-normative documentation (NTC - Italian National Building Code, 2018 and AGI - Guidelines of Italian Geotechnical Association, 2005) and scientific documentation, while the verification of innovative methodologies belongs to other situations.

The diagram represented in figure 1 is applicable to all possible seismic instabilities (landslides, liquefactions, active and capable faults and differential settlements). It summarise the activities, expected results and type of zone susceptible to instability at the different levels of study of seismic microzonation. Also worthy of mention is the opportunity of standardising the identification, significance and denomination of zones susceptible to instability that, as the diagram shows, are of three types:

- Attention Zones (AZ) in SHM Map studies
- Susceptibility Zones (SZ) in SM Map studies
- Respect Zones (RZ) in SM Map studies.

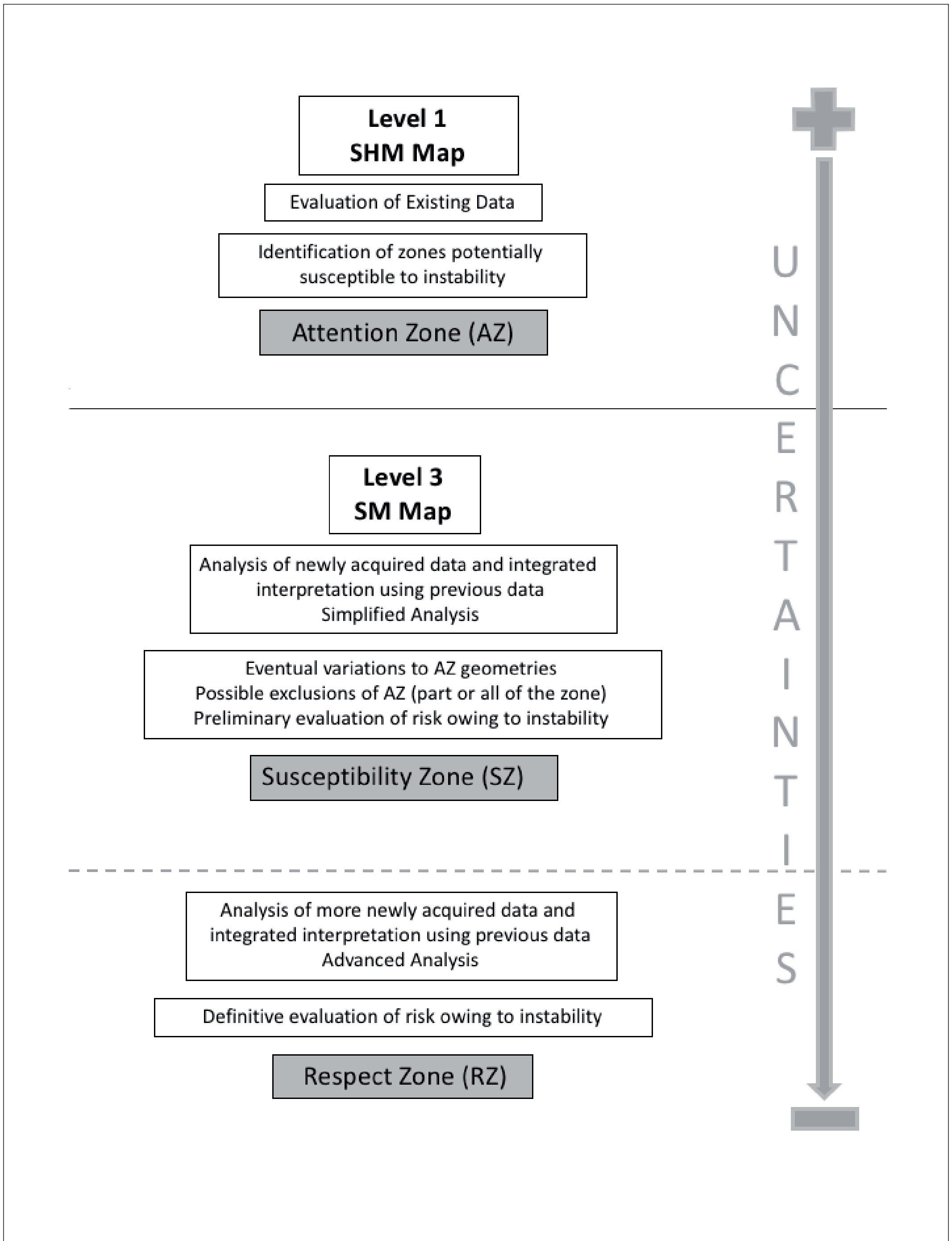


Figure 1 → Illustrative diagram of instability zone types in SHM Maps and SM Maps. Data gathering and analyses permit a reduction in uncertainties from Level 1 to Level 3.

In conceptual terms, the significance of the three zones is as follows:

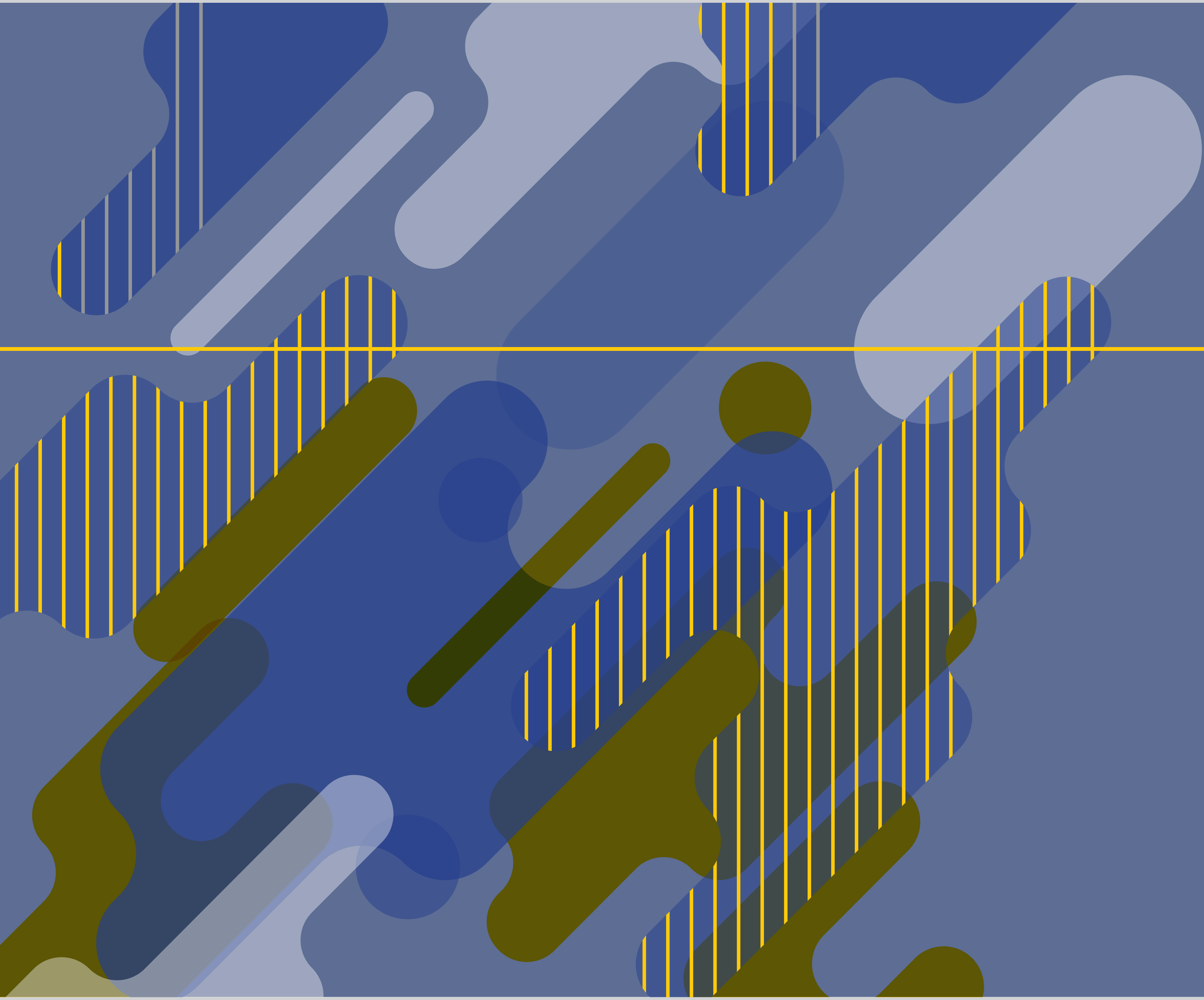
- **Attention Zones (AZ):** zones in which available data indicate the presence of conditions suggesting instabilities, though not sufficient, in quantity and typology, for defining whether this instability may occur in the event of an earthquake; nonetheless, it is possible, for example by consulting inventories, to establish the presence and/or occurrence of eventual phenomena during past earthquakes.

In any case, it is worthwhile, even during this phase, proceeding with original in situ or laboratory tests, when available information is deemed insufficient.

- **Susceptibility Zones (SZ):** areas in which it is possible to provide a quantitative estimate of hazard following the collection of specific data relative to the instability being studied and the application of methods of analysis, in many cases simplified (to permit the application of results to a vast area).
- **Respect Zones (RZ):** areas in which it is possible to reliably quantify hazard following the collection of specific data relative to other instabilities being studied and the application of methods of analysis, in many cases advanced (detailed analyses of limited and/or particularly important areas).

The difference between a Susceptibility Zone and a Respect Zone, at the end of a study, is given other than by the application of methods of analysis ("advanced" in an RZ), by the diverse level of hazard (higher in an RZ). It is expressed by a specific parameter describing the instability considered (active and capable fault, liquefaction, landslide).

This document is subdivided into two parts:
PART ONE, which defines the physical phenomenon of liquefaction and outlines a technical-operative procedure for establishing the form and dimensions of areas affected by this phenomenon.
PART TWO, which provides land use guidelines for urban planning and construction in areas affected by this phenomenon.
The **APPENDIXES** provide a selection of calculations complementary to the text.
The present guidelines were approved by the Technical Commission on Seismic Microzonation (article 5, comma 7, OPCM 13 November 2010, n. 3907), during a meeting held on 2 March 2017. An integration and closer examination of the Guidelines for Seismic Microzonation, they are made available to the Regions and Autonomous Provinces so that they can be used as an operational tool to define the prescribed level.
The structure of the present document is analogous to that adopted for the Land Use Guidelines for Areas With Active and Capable Faults (ACF), approved by the Conference of Regions and Autonomous Provinces during a meeting held on the 7 May 2015. In particular, Part Two, governing Land Use Planning, contains the same structure of indications for urban planning and building activities.



DESCRIPTION OF THE PHYSICAL PHENOMENA AND LIQUEFACTION ZONES

PART I

1 GENERAL TERMINOLOGY

The term "liquefaction" refers to various physical phenomena (free field liquefaction, cyclical mobility, flow liquefaction) observed in sandy deposits and saturated sandy slopes during strong earthquakes ($M_w \geq 5$). They share the development of conditions that hinder drainage, leading to an increase in and accumulation of interstitial pressures that may provoke a drastic drop in shear resistance and, consequently, a loss in soil bearing capacity.
In particular, the following can be defined in relation to the geometry of the problem:

- **Free Field Liquefaction:** a phenomenon of instability in the absence of static shear forces.

The following are defined in relation to the severity of the event and in the presence of static shear forces:

- **Cyclic Mobility** a phenomenon of instability in the presence of static shear forces inferior to post-seismic shear resistance;
- **Flow Liquefaction** a phenomenon of instability in the presence of static shear forces superior to post-seismic shear resistance.

The effects of liquefaction vary widely in relation to the severity of the event, geometric conditions and initial stress conditions.
In *free field* conditions there is a general prevalence of the following phenomena:

- craters, small volcanoes (sand boils), leaking water and sand;
- large oscillations and ruptures of the earth;
- drops and rises in the earth.

The severity of these phenomena grows together with the intensity of the earthquake, the size of the area subject to liquefaction and the reduction in the depth of the water table.
In the presence of static shear forces there is instead a prevalence of the following phenomena:

- horizontal movements of the earth *(lateral spreading)*;
- movements of fluid masses/collapse of natural and artificial slopes;
- loss of foundation bearing capacity;
- floating of subterranean works;
- collapse of support structures and harbour quays.

In its strictest definition (fluidification or solifluction), liquefaction causes significantly more severe effects than those which can be observed in the event of cyclical mobility.

2 MAPS, LEVELS OF SEISMIC MICROZONATION AND LIQUEFACTION ZONES

This part of the document pursues the following objectives:

- avoid the identification of Liquefaction Susceptible Zones in SM studies when sufficiently reliable data has not been gathered;
- define standard procedures for the identification of Liquefaction Zones based on the typology and quality of investigations carried out and methods of analysis;
- specify the level of uncertainty of the results;
- define a system for representing Liquefaction Zones.

Susceptibility to liquefaction is defined in reference to free field conditions.
Technical-scientific literature (i.e. JGS, 1998; Youd and Perkins, 1978; Kramer, 1996), to which the current Italian legislation (NTC, 2018) refers, demonstrates that the phenomenon of liquefaction may occur under the following conditions:

- earthquakes with a moment magnitude of Mw ≥5. The moment magnitude is tied to the duration of the event and the number of cycles of seismic loading and unloading to which the ground is subjected during the event. These factors are determinant to the verification of the phenomenon;
- maximum surface acceleration under free field conditions (a_{max}) of at least 0.10g (not to be confused with the acceleration of rigid and morphologically flat terrains, as per NTC08, denominated a_g);
- the presence of predisposing geological and geotechnical characteristics (the most important being the presence of terrains consisting primarily of saturated sands and limes, in the water table, of a low density for the first 20 metres of depth).

When describing the constituent lithotypes of the subsoil in the area of interest, the Geo-Technical Map for Seismic Microzonation (GTM_SM) plays a fundamental role in identifying the presence, or lack, of predisposing local conditions of liquefaction (third point of the previous list). Hence, this map must also represent elements of paleogeography (i.e. paleo trenches, even buried) and eventual anthropic elements of interest (i.e. riverbanks).

The GTM_SM represents a truly propaedeutic study for the identification of Liquefaction Zones. In particular, an area in which the presence of non-cohesive terrains is hypothesised in the first 20 meters below the ground is to be identified in the GTM_SM and accompanied by a specific description in the notes as an area requiring further investigation to verify the effective presence of underlying conditions that may give rise to phenomena of liquefaction.

The following levels of investigation **(Table 1)** serve to identify areas potentially interested by phenomena of liquefaction, described in the present document:

- **Level 1** (SHM Map) for the identification of Attention Zones for Liquefaction (AZ_{LQ}), which makes use of the Minimum informative elements[1] (lithostratigraphy, fault depth, paleogeographic elements, etc.);
- **Level 3** (SM Map) which distinguishes two methods of further investigation in relation to two typologies of areas:
  - ***Liquefaction Susceptible Zone*** (SZ_{LQ}), to be identified based on specific informative elements and simplified methods of calculation;
  - ***Liquefaction Respect Zone*** (RZ_{LQ}), to be identified based on specific informative elements and advanced methods of calculation.

The estimates of the average Liquefaction Potential Index for an area (LPI, defined in chapter 2.3) are to be developed at Level 3. In fact, this parameter requires specific analyses and more in-depth investigations. The results of studies at Level 2 (schedules), under particular geological subsoil conditions, may instead be utilised only to calculate the maximum surface acceleration (a_{max}) and in the SM Maps that serve to characterise the SZ_{LQ} and RZ_{LQ}.

It is possible to note that diverse types of liquefaction zones belong to different levels of investigation. Each zone corresponds with indications for urban planning and transformations (explored in **PART II**).

SM LEVEL	MAP	LIQUEFACTION ZONES	AVAILABLE INFORMATION	METHODS
1	SHM	ATTENTION ZONES (AZ_{LQ})	MINIMUM	–
3	SM	SUSCEPTIBILITY ZONES (SZ_{LQ})	SPECIFIC	SIMPLIFIED (*SENSU* AGI, 2005)
3	SM	RESPECT ZONES (RZ_{LQ})	SPECIFIC	ADVANCED (*SENSU* AGI, 2005)

Table 1 → Levels, maps and corresponding types of liquefaction zones.

Figure 2 represents a flow diagram illustrating the methodological approach, described in the following paragraphs, for identifying the three types of Liquefaction Zones.

1 Minimum informative elements also include previous information.

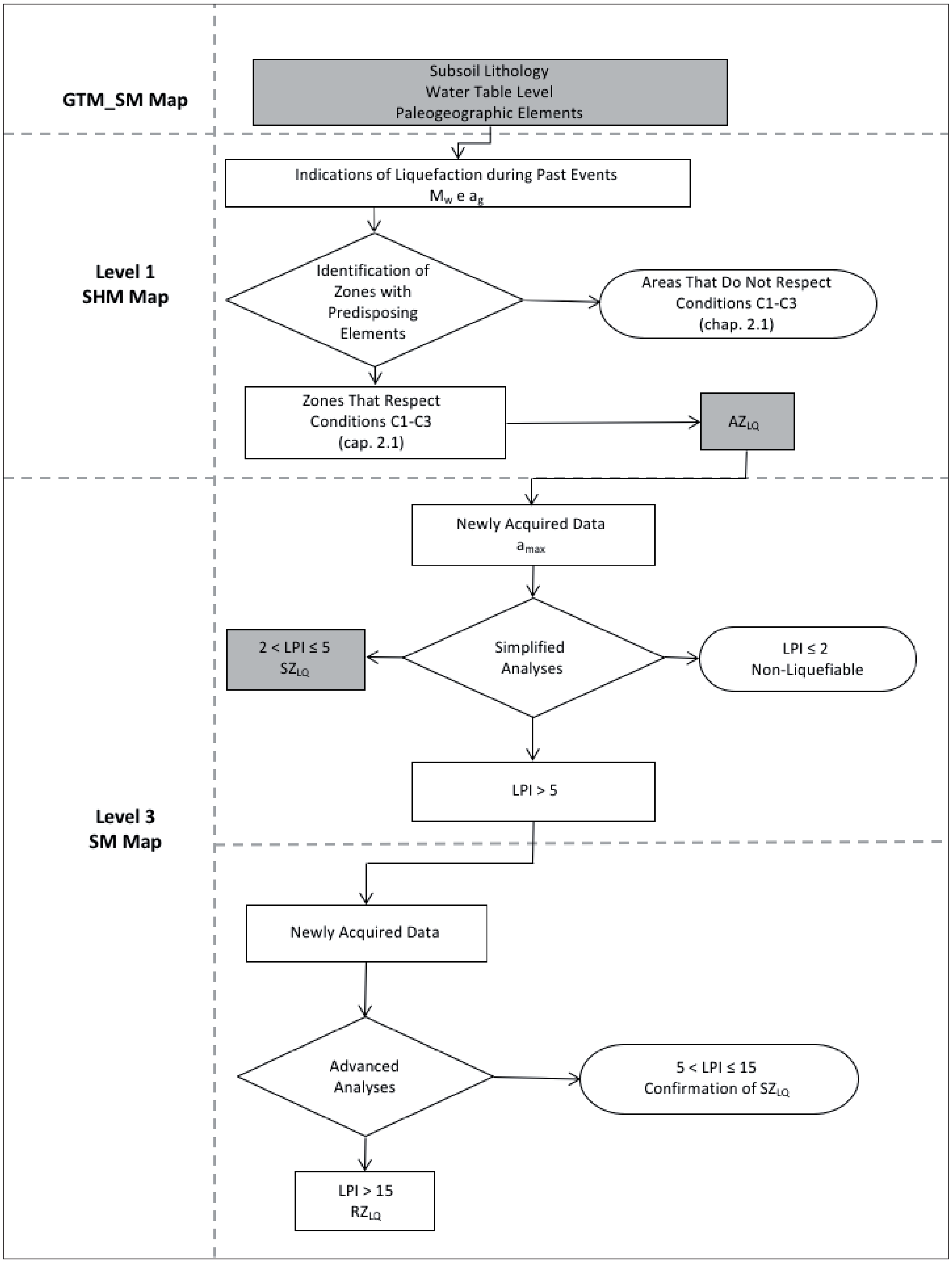


Figure 2 → Flow diagram of the methodological approach (through the levels of SM) to defining Liquefaction Zones. GTM_SM: Geo-Technical Map for Seismic Microzonation; a_g: acceleration in free field rigid and flat rock; Conditions C1-C3: see chapter 2.1; a_{max}: maximum surface acceleration, calculated through numerical analysis; LPI: average Liquefaction Potential Index (see chapter 2.3); AZ_{LQ}: Liquefaction Attention Zone; SZ_{LQ}: Liquefaction Susceptible Zone; RZ_{LQ}: Liquefaction Respect Zone.

2.1 Conditions for Liquefaction

- Phenomena of liquefaction develop in the subsoil in the presence of the following 3 conditions (a partially modified reference to the indications found in AGI, 2005 and NTC, 2018):
- **C1. the lithological succession presents** layers of non-cohesive saturated soil (sandy limes, sands, limey sands, gravely sands, clayey sands and sandy gravels) at a depth of less than 20 meters below the surface. In the presence of data it is possible to proceed with a more analytical survey of the **presence within the lithological succession** of non-cohesive layers of soil containing particles with a diameter in the granulometric range of **Figure 3**;
- **C2.** the **water table** must be located at an average seasonal depth of less than 15 m below the ground;
- **C3. expected seismic events must be characterised by magnitude values of Mw ≥ 5 (*Irif* ≥ VII) and a reference surface acceleration of a_{max} ≥ 0.1 g (I_{MCS} ≥ VII)**.

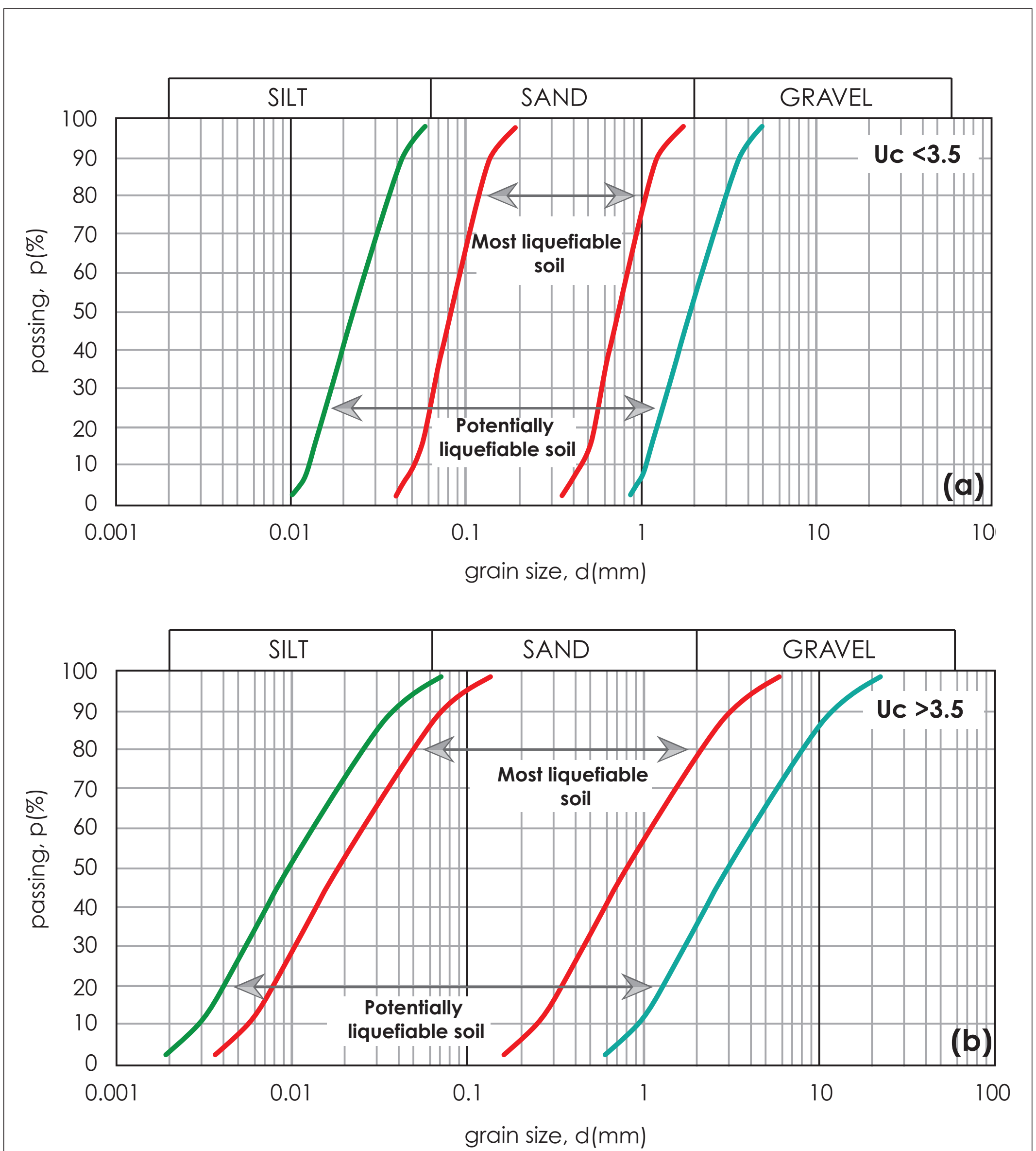


Figure 3 → Granulometric ranges for the preliminary evaluation of the susceptibility to soil liquefaction, for soils with a uniform (a) and extended (b) granulometry (from Sherif and Ishibashi, 1977, cited in AGI, 2005).

The possibility that a given seismic event is capable of triggering phenomena of liquefaction depends on the intensity and duration of expected shaking. The determination of these elements begins with an analysis of seismic risk using probabilistic models, focused on calculating the level of verisimilitude associated with diverse possible expected levels of movement, beginning with data relative to past earthquakes and other data (seismogenetic zones, attenuation relations, etc.).

Appendix A1 lists a selection of methods for calculating magnitude for verifying conditions that may give rise to liquefaction.

2.2 SHM Map – Level 1 (AZ_{LQ} - Attention Zones)

At Level 1, the verification of the 3 conditions for liquefaction described above is carried out using the **minimum informative elements**. Some of these elements, which refer to the characteristics of the subsoil, must be collected giving priority to areas already indicated in the GTM_SM.
When the 3 conditions are verified, it is necessary to identify a zone potentially susceptible to liquefaction and to qualify it as AZ_{LQ} (Attention Zone).
Regarding the evaluation of condition C1, as it is based on pre-existing data which may not always include granulometric indications, it is possible to refer also to the purely lithological descriptions found in pre-existing technical reports on continuous perforation tests or through the direct analysis of core samples.
The same reference to pre-existing technical reports is possible for condition C2.
To verify condition C3, as specific amplification studies are not generally present at this level of investigation, for the minimum threshold value for this condition it is possible to use only the magnitude value by making reference to Appendix A1.
Obviously, when values of a_{max} are available they should be used directly.

In the event that none of the conditions C1 to C3 are verified, the area is to be considered not susceptible to liquefaction.
AZ_{LQ} are represented using diverse symbols on the SHM Map.
The identification of these zones mandatorily refers to the next level of investigation (SM Map – Level 3).

At Level 1, in addition to identifying AZ_{LQ}, the Descriptive Report must also include indications about:

- geological, hydrogeological and geomorphological conditions of the area;
- eventual indications of liquefactions during past earthquakes;
- the location and typology of investigations to be carried out at successive levels of investigation;
- methods of analysis to be adopted at successive levels of investigation.

The SHM Map must in any case identify those areas for which certain information exists regarding the effects of liquefaction following a historic and/or recent earthquake. These zones must always be characterised as AZ_{LQ}.

Information regarding the phenomena of liquefaction observed during historic earthquakes can be found in scientific publications or in the CEDIT catalogue: *Italian Catalogue of Seismic Ground Failures (http://www.ceri.uniroma1.it/index_cedit.html, 2017).*

Chapter 3 describes the criteria for establishing the perimeter of AZ_{LQ}.

2.3 SM Map - Level 3 (SZ_{LQ} - Liquefaction Susceptible Zones)

For the SM Map (Level 3) it is necessary to collect specific data and to apply generally simplified methods of analysis to produce quantitative estimates of hazard. The acquisition of specific geotechnical test results, in situ or in the laboratory, pursues the following objectives:

- estimating the lithostratigraphic surface amplification (surface amax in free field conditions) using numeric models or, for particular subsoil conditions, using lithostratigraphic amplification schedules;
- using more accurate data to define the geometry of the zone in which liquefaction is possible;
- using simplified analyses to attribute a medium Liquefaction Potential Index[2] (LPI)[3], divided into four classes:

LPI	CLASSES
$0 < LPI \leq 2$	None-Low
$2 < LPI \leq 5$	Moderate
$5 < LPI \leq 15$	High
$LPI > 15$	Very High

Table 2 → **Medium Liquefaction Potential Index (LPI) and Relative Classification.**

- estimating the uncertainties in results obtained from in situ and laboratory analyses and methods for analysing susceptibility;
- defining the areas of SZ_{LQ} ($2 < LPI \leq 15$);
- defining the areas of RZ_{LQ} ($LPI > 15$); for these zones it is opportune to conduct further investigations to confirm the RZ_{LQ}.

2 Medium LPI is the average of the LPI calculated in all verticals inside the zone.

3 The liquefaction potential index LPI, is defined by the following formula:

$$= \int_0^{20} F(z)\, w(z) dz$$

where z is the depth below grade in meters and $w(z) = 10 - 0.5z$ At a given level z the factor F(z) has the following value:
$F = 1 - F_L$ if $F_L \leq 1.0$
$F = 0$ if $F_L > 1.0$
where F_L is the liquefaction safety factor at the level considered.

Those zones where the 3 conditions for liquefaction have been identified at Level 1 and where the verticals analysed using simplified analysis present an LPI greater than 2 and inferior or equal to 15, are Liquefaction Susceptible Zones (SZ_{LQ}), in turn distinguished in the maps in terms of medium ($2 < LPI < 5$) and high ($5 < LPI < 15$) hazard zones.
Those zones where the 3 conditions for liquefaction have been identified at Level 1 and where the verticals analysed using simplified analysis present an LPI greater than 15, are Respect Zones (RZ_{LQ}). Further investigations can be used to determine whether they are RZ_{LQ}, or SZ_{LQ} (Chapter 2.4).

The SZ_{LQ} are represented on the SM Map (Level 3).
Chapter 3 illustrates the criteria for defining SZ_{LQ} zone perimeters.

2.4 SM Map - Level 3 (RZ_{LQ} - Liquefaction Respect Zones)

On the SM Map (Level 3), to reliably quantify hazard it is necessary to collect specific data and to apply methods that, in the majority of cases, are highly advanced. This makes it possible to identify the Liquefaction Respect Zones (RZ_{LQ}). The *in situ* collection of data, laboratory tests and dynamic analyses (specific available information) designed to identify Liquefaction Respect Zones (RZ_{LQ}) have the following objectives:

- using numeric simulations (if this has not already been done as part of the identification of the SZ_{LQ}) to evaluate amax;
- re-evaluate the medium LPI for zones with an LPI >15, using additional data and/or simplified or advanced dynamic analyses;
- estimate the uncertainties of the results obtained from *in situ* and laboratory testing, and analyses;
- evaluate or re-evaluate the possible effects on manmade works of interest and provide indications relative to possible interventions to mitigate risk (see **Appendix A2**).

Areas where verticals analysed using dynamic methods presenting a medium LPI greater than 15, are confirmed as Respect Zones (RZ_{LQ}).
Areas where verticals analysed using dynamic methods presenting a medium LPI lesser than or equal to 15, are labelled as Liquefaction Susceptible Zones (SZ_{LQ}).
RZ_{LQ} are to be represented on the SM Map (Level 3).
Table 3 offers a summary for the verification of conditions used to identify different zones.
Chapter 3 illustrates the criteria for defining zone perimeters.

C1	C2	C3	LPI	ZONE	MAP	SM LEVEL
Yes	Yes	Yes	–	AZ_{LQ} (Attention Zone)	SHM	1
Yes	Yes	Yes	$2 < LPI \leq 15$	SZ_{LQ} (Susceptible Zone)	SM	3 (under some geological conditions Level 2, limited to a_{max})
Yes	Yes	Yes	> 15	RZ_{LQ} (Respect Zone)	SM	3

Table 3 → Summary table of the verification of conditions for the identification of different zones.

Regardless of the choice of *in situ* investigations, laboratory testing and methods of analysing the Liquefaction Potential, particular attention must be paid to the coherence within the different methods adopted of the choice of parameters, and their use in different analyses.

3 METHODS OF REPRESENTING AND DEFINING ZONE PERIMETERS

3.1 Methods of Representing Different Zones

Unstable zones due to liquefaction must be mapped at a suitably detailed scale, preferably not less than 1:5,000.

The AZ_{LQ} are zones represented on the SHM Map and, when Level 2 studies are made to define litho-stratigraphic amplifications, they must also be shown on SM Maps. In fact, when SM Maps represent zones at Level 2, when this level is not surpassed, are often assumed as reference maps for urban planning, making it important to conserve information about the AZ_{LQ} identified.

The SZ_{LQ} and the RZ_{LQ} are to be represented on SM Maps (Level 3).

The RZ_{LQ} may be inside an SZ_{LQ}, though they never overlap.

3.2 Methods of Defining Zone Perimeters

In general terms, the information guiding the definition of zone perimeters, are taken from the following material (listed in decreasing order of importance (reliability):

- **a)** descriptions of physical phenomena surveyed on site, if during the immediate post-event phase;
- **b)** indications of phenomena of liquefaction during historic events (historic sources);
- **c)** evaluations made using dynamic methods (advanced and simplified);
- **d)** evaluations made using simplified methods.

This information is used to define the following procedures of defining zone perimeters.

1) AZ_{LQ} (SHM Map)

The Attention Zone (AZ_{LQ}) is identified based on the **Minimum Informative Elements** and thus the perimeter must take this level of uncertainty into account.

The limits of the AZ_{LQ} coincide with the limits of the zones **(Fig. 4)** where conditions from C1 to C3 have been identified.

These conditions may also be defined on the basis of:

- indications of phenomena of liquefaction during historic and pre-historic events (historic sources and evidence found in excavations, trenches and paleosismological studies);
- GTM_SM (scale 1:5,000-1:10,000);
- *in situ* investigations and laboratory analyses.

The perimeterization procedure foresees that:

- as part of the development of the SHM Map, the AZ_{LQ} are identified among those susceptible to amplification (in other words, those zones where C1 to C3 conditions have been verified, in particular the presence in the first 20 m of the lithostratigraphic succession of loose and granular sediments and a superficial water table);

- an AZ_{LQ} may consist of one or more zones susceptible to amplification, some of which may share the same boundary **(Fig. 5)**;
- the AZ_{LQ} must be characterised by the lithostratigraphic succession of the subsoil.

For more on the methods of representing the AZLQ refer to the Graphic and Data Archiving Standards version 4.1 *(http://www.protezionecivile.gov.it/jcms/it/standard_studi_ms.wp)*.

The AZ_{LQ}, represented on the SM Maps where investigations do not exceed Level 2, will always be characterised by a lithostratigraphic succession.

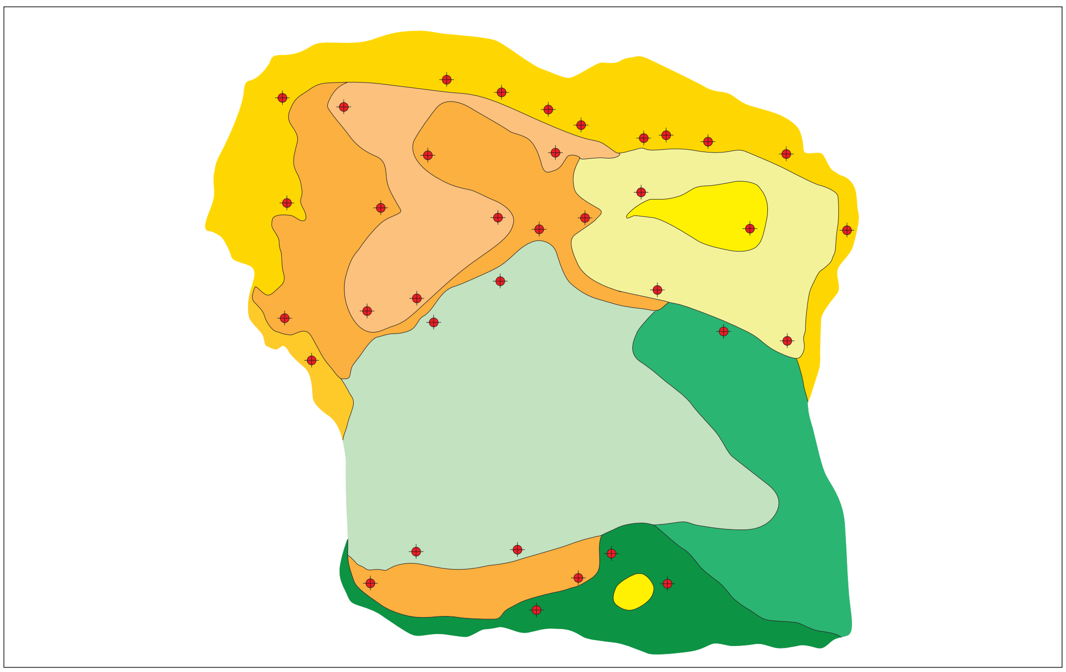


Figure 4 → **Example of an SHM Map. All zones are "susceptible to amplification" (soft soils above geological bedrock). The red dots represent the location of investigations that allowed for the identification of different zones (the symbol indicates a generic investigation and has no reference to the symbology used in the Graphic and Data Archiving Standards). The 3 conditions described in Chapter 2.1 have not yet been analysed at this stage.**

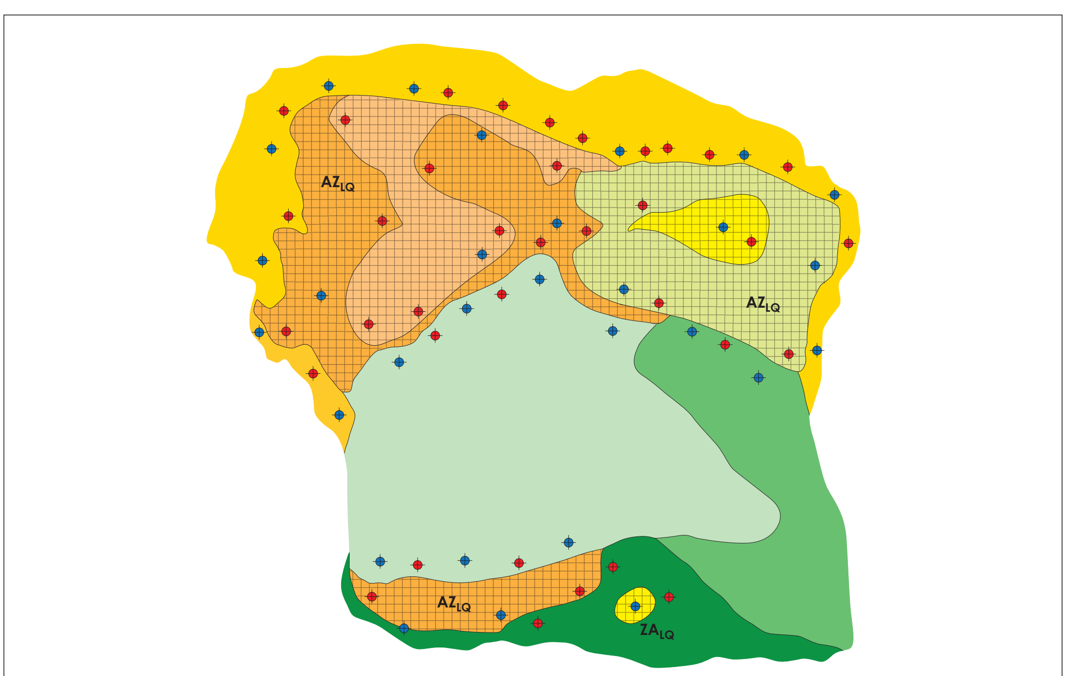


Figure 5 → **Example of an SHM Map that identifies the AZ_{LQ} (grey hatch) respecting the 3 conditions described in Chapter 2.1. The blue dots represent the location of investigations to be made at Level 3 (the symbol indicates a generic investigation and has no reference to the symbology used in the Graphic and Data Archiving Standards).**

2) SZ_{LQ} (SM Map)

The Susceptibility Zone (SZ_{LQ}) does not necessarily coincide with the Attention Zone (AZ_{LQ}; **Figure 6**).

The perimeter of the SZ_{LQ} is based on:

- GTM_SM re-elaborated based on new investigations at a greater scale of detail (1:5,000-1:1,000);
- results of simplified analyses for the calculation of CRR (Cyclic Resistance Ratio) and CSR (Cyclic Shear Stress Ratio), using different tests and investigations, with varying levels of uncertainty.

The procedure for defining the perimeter of SZ_{LQ} **(Fig. 6)**, beginning with the AZ_{LQ} defined at Level 1, foresees the:

- re-evaluation of information contained in the GTM_SM;
- calculation of amax at the surface using numeric methods;
- evaluation of LPI based on the results of the verticals studied and the verification that LPI >2;
- geometry of the SZ_{LQ};
- calculation of the medium LPI in the SZ_{LQ} zone.

The SZ_{LQ} will be characterised by the medium LPI and by an amplification factor.

When LPI >15, the zone is classified as an RZ_{LQ}.

For more on the methods of representing the SZ_{LQ} refer to the Graphic and Data Archiving Standards version 4.1.

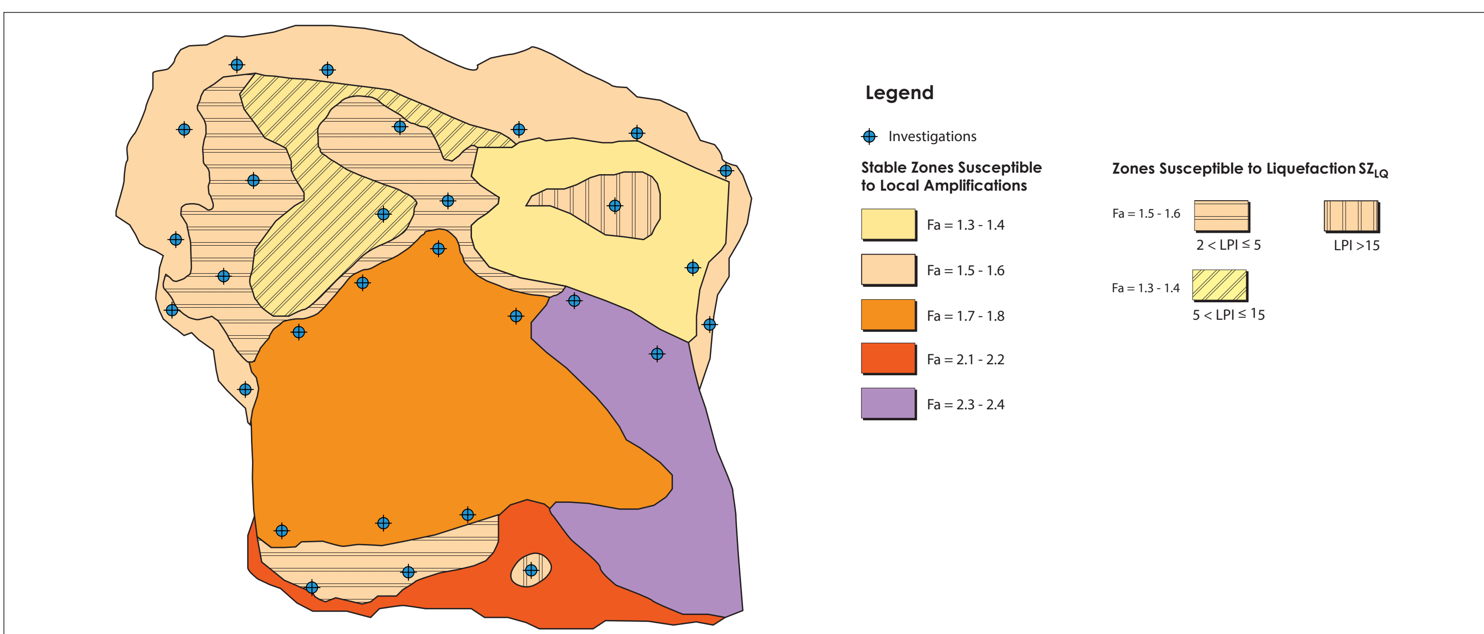


Figure 6 → Example of an SM Map with some SZ_{LQ} (LPI > 2). The blue dots represent the location of investigations whose results made it possible to define the perimeter of the SZ_{LQ} (the symbol indicates a generic investigation and has no reference to the symbology used in the Graphic and Data Archiving Standards). The SZ_{LQ} hatch indicates the medium LPI class, and the background colour represents the amplification parameter class.

3) RZ_{LQ} (SM Map)

The perimeterization of the RZ_{LQ} **(Fig. 7)** is based on the positions of the verticals used for investigations and analyses, where LPI >15.

The perimeterization of the RZ_{LQ} occurs at the same time as the identification of the SZ_{LQ}.

It is necessary to apply one of the methods of dynamic analyses of liquefaction susceptibility to the verticals used for investigations and analyses present inside the RZ_{LQ}:

- simplified dynamic analysis of total or effective tensions;
- advanced dynamic analysis.

This determines:

- the calculation of seismic wave action across the site (including amplification factors)
- the evaluation of the LPI based on the results of the verticals studied and the verification that it is >15;
- the geometry of the RZ_{LQ};
- the calculation of the medium LPI in RZ_{LQ};

The RZ_{LQ} will be characterised by the medium LPIs as well as an amplification factor.
When the LPI is lesser than or equal to 15, the zone is to be represented as an SZ_{LQ}.

For more on the methods of representing the RZ_{LQ} refer to the Graphic and Data Archiving Standards version 4.1.

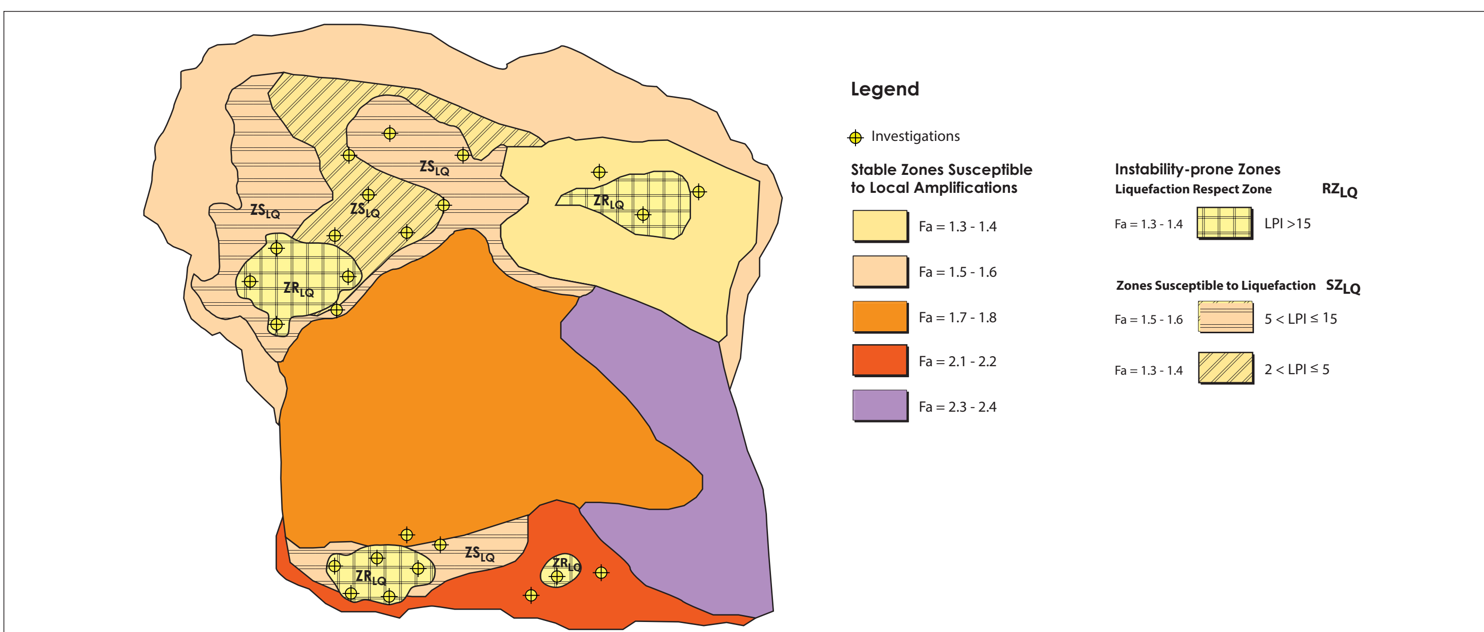
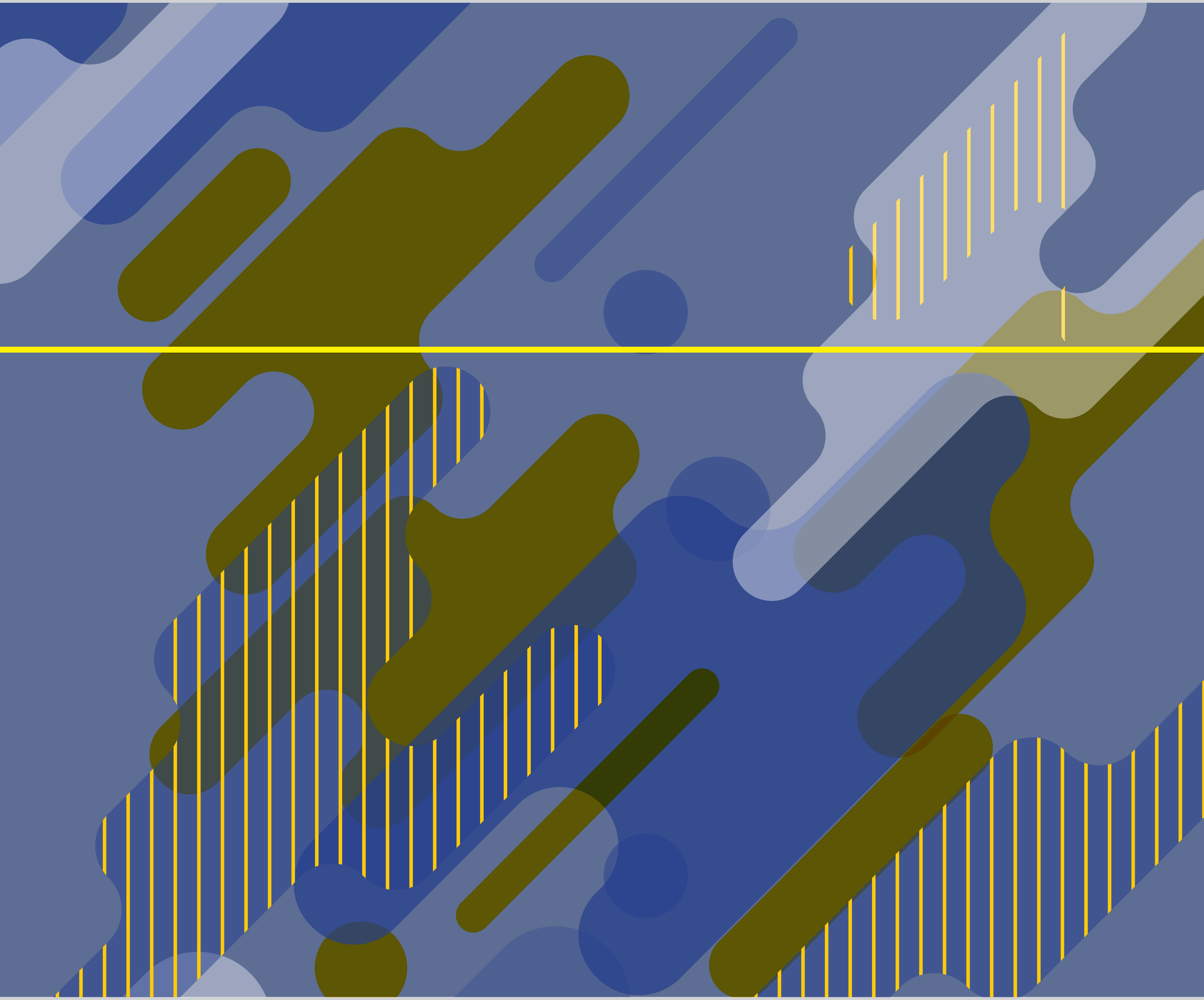


Figure 7 → Example of an SM Map with some SZ_{LQ} (2 < LPI ≤ 15) and RZ_{LQ} (LPI > 15). The yellow dots represent the location of investigations whose results made it possible to define the perimeter of the RZ_{LQ} (the symbol indicates a generic investigation and has no reference to the symbology used in the Graphic and Data Archiving Standards). The background colour represents the amplification parameter class.

Appendix A2 offers a look at some methods for mitigating the risks deriving from liquefaction.
Appendix A3 illustrates the methods of intervention adopted by the CPD and the Region of Emilia-Romagna in the wake of the May 2012 earthquake.



LAND USE GUIDELINES FOR LIQUEFACTION ZONES

Part II

4 IDENTIFICATION OF CATEGORIES OF URBAN AREAS AFFECTED BY LIQUEFACTION

Urban and territorial planning in areas affected by liquefaction is required to regulate land uses and urban development forecasts in light of the relationship between seismic hazard and diverse contexts of settlement.

As part of urban planning instruments, SM studies, at various levels, as defined in the GSM (2008), are to be integrated with the contents of the present guidelines.

The definition of these guidelines refers conventionally to **three categories of urban areas**:

- **Developed Areas** (recent or consolidated)
- **Undeveloped Areas** (with plans for development)
- **Undeveloped Areas** (with no plans for development)

Each of these three categories is defined by specific characteristics of settlement, infrastructures and uses, whose relations with the presence of AZ_{LQ}, SZ_{LQ} and RZ_{LQ} are to be subjected to specific regulations. In particular, the three categories of urban areas may be defined as follows:

- **Developed Areas** (recent or consolidated)
  Urbanised and Developed Areas of varying levels of completion, consolidation and layering. They include historic centres, consolidated fabrics, areas of completion with residential, manufacturing, tertiary and mixed uses.
- **Undeveloped Areas** (with plans for development)
  Undeveloped Areas, partially Developed Areas or areas for planned new settlements – residential, manufacturing, tertiary or mixed use – of buildings, infrastructures and networks. These areas may be found in adjacency to settled areas, or in still un–urbanised contexts.
- **Undeveloped Areas** (with no plans for development)
  Unbuildable areas, or areas with limits on development due to use (agricultural lands), or owing to the presence of restrictions or forms of protection.

These three categories must be related to the forecasts contained in applicable urban planning instruments and to their actual implementation.

With regards to specific content and structure of planning regulations in these areas, each Region will be able to plan suitable matches between the three urban categories and the homogenous areas identified by their respective urban planning instruments.

5 LAND USE PLANNING GUIDELINES

Land Use Planning Guidelines and forecasts for transformations in areas subject to liquefaction must take into account two factors:

- instability owing to liquefaction may affect relatively vast areas of a territory (in some cases that of an entire town);
- it is possible to implement specific interventions to reduce levels of hazard, including direct interventions on the ground, and vulnerability, through interventions involving buildings (as illustrated in **Appendix A3**).

In light of this, the land use planning guidelines and forecasts for transformations in Liquefaction Zones are articulated according to **two types of indications**:

- **indications for urban planning**, when specific regulations are imposed by urban planning instruments, including categories of intervention and allowable uses and methods of implementation;
- **indications for buildings**, referencing earthquake resistance regulations to define possible categories of intervention based on classes of use for existing and new constructions[4].

A table of different types of urban planning indications is proposed with reference to the three urban areas categories defined above and the Liquefaction Zones in which they fall **(Table B1)**. A column related to infrastructure is reported in the table as a distinct scope, which was not studied in depth here. **Appendix B2** presents a brief outline of classification.

URBAN PLANNING CATEGORIES		DEVELOPED AREAS (RECENT OR CONSOLIDATED)	UNDEVELOPED AREAS (WITH PLANS FOR DEVELOPMENT)	UNDEVELOPED AREAS (WITH NO PLANS FOR DEVELOPMENT)	INFRASTRUCTURES
Liquefaction Zones	AZ_{LQ}	Mandatory In-Depth Analyses (5.1.1)	Mandatory In-Depth Analyses (5.2.1)		Infrastructure Program (5.3)
	SZ_{LQ}	Instability-prone Zones Program (5.1.2)	Limited Intervention (5.2.2)		
	RZ_{LQ}				

Table B1 → Urban Planning Guidelines (paragraph references in parentheses).

4 Chapter 2, paragraph 2.4.2 of the NTC (Norme tecniche per le costruzioni, National Building Code) from 2018 lists the following Classes:
Class I: Constructions only occasionally occupied by people and agricultural buildings.
Class II: Constructions with normal occupancy levels that do not contain environmentally harmful material or essential public and social functions. Industries whose activities are not harmful to the environment. Bridges, infrastructures, mobility networks that do not belong to Class III or IV, railway networks whose interruption would not be cause for an emergency. Dams whose collapse would not provoke relevant consequences.
Class III: Constructions with significant occupancy levels. Industries whose activities are harmful to the environment. Extra-urban mobility networks that do not belong to Class IV. Bridges and railway networks whose interruption would be cause for an emergency situation. Dams whose collapse would provoke relevant consequences
Class IV: Constructions containing important public or strategic functions, also in relation to the management of civil protection functions in the event of calamities. Industries whose activities are particularly harmful to the environment. Type A or B mobility networks, as per Ministerial Decree n. 6792 from 5 November 2001, "Norme funzionali and geometriche per la costruzione delle strade" (Functional and Geometric Guidelines for Road Construction), and type C when they belong to routes connecting provincial capitals not served by roads classifiable as type A or B. Bridges and railway networks of critical importance to maintaining communication routes, in particular in the wake of an earthquake. Dams linked to the functioning of aqueducts and hydroelectric facilities.

5.1 Developed Areas

5.1.1 Mandatory In-Depth Analyses (Developed Areas)

For AZ_{LQ}, in Developed Areas (recent or consolidated) for new constructions (on empty lots) and interventions involving existing buildings, the necessary geological and geotechnical investigations must be completed at Level 3 SM (paragraphs 2.2 and 2.3 of PART ONE) to identify SZ_{LQ} and RZ_{LQ}, or for specific interventions, the investigations mandated by applicable technical regulations. It is a prerogative of the Regions to define possible time limits, depending on available resources, for the completion of these investigations. In the absence of in-depth analysis the following guideline is to be applied:

Construction	Intervention Type	Description
Existing	Limited	Excluding regular maintenance, hygiene-health related upgrades, or other mandatory sector-specific interventions, all other types of intervention must provide seismic upgrading and/or retrofitting and evaluation of interventions to reduce hazard (conforming to current regulations).
New Construction	Prohibited	New construction is not permitted..

5.1.2 Instability-prone Zones Program

For SZ_{LQ} and RZ_{LQ} in **Developed Areas (recent or consolidated)**, within the scope of their own urban planning instruments and according to ordinances and directions of higher-level subjects, local authorities must identify and pursue one or more objectives of the *Instability-prone Zones Program (IZP)*, assuming the contents in their appropriate form to mitigate conditions of risk. The IZP is a complex program of interventions that defines objectives and areas of intervention, together with feasibility and implementation procedures. The IZP concerns all areas susceptible to instability in general, including those also affected by active and capable faults (ACF)[5]. **Appendix B1** contains a Program outline that can also be used as a checklist of the topics covered. In the absence of an IZP the same guideline adopted for AZ_{LQ} is to be applied (paragraph 5.1.1).

5.1.2.1 IZP Objectives

The definition of a specific IZP implies the choice of one of the following objectives, differentiated as a function of SZ_{LQ} and RZ_{LQ}:

- Limited Intervention (Objective 1)
- Mandatory or Limited Intervention (Objective 2)
- Mandatory or Prohibited Intervention(Objective 3)
- Prohibited Intervention (Objective 4)

The respective guidelines for each of these objectives are listed below.

5 Technical Commission on Seismic Microzonation. *Land Use Guidelines for Areas with Active and Capable Faults*. Version 1.0. Civil Protection Department and Conference of Italian Regions and Autonomous Provinces. Rome, May 2015.

5.1.2.1.1 – 1st Hypothesis: Limited Intervention (Objective 1)

The choice of this objective is subject to the following guidelines:

Construction	Intervention Type	Description
Existing	Limited	Excluding regular maintenance, hygiene-health related upgrades, or other mandatory sector-specific interventions, all other types of intervention must provide seismic upgrading and/or retrofitting and evaluation of interventions to reduce hazard (conforming to current regulations).
New Construction	Limited	New construction is allowed with an evaluation of interventions designed to reduce hazard (in conformity with applicable regulations).

5.1.2.1.2 – 2nd Hypothesis: Mandatory or Limited Intervention (Objective 2)

The choice of this objective is subject to the following guidelines:

Construction	Intervention Type	Description
Existing	Mandatory	Relocation is not mandatory, but preferred. Mandatory interventions (within the periods of time imposed by Regional Governments): upgrading and/or modernisation works and/or local strengthening and evaluation of interventions to reduce hazard (in conformity with applicable regulations), independent of requests to proceed with maintenance or other works.
New Construction	Limited	New construction is allowed with an evaluation of interventions designed to reduce hazard (in conformity with applicable regulations).

5.1.2.1.3 – 3rd Hypothesis: Mandatory or Prohibited Intervention (Objective 3)

The choice of this objective is subject to the following guidelines:

Construction	Intervention Type	Description
Existing	Mandatory	Relocation is not mandatory, but preferred. Mandatory interventions (within the periods of time imposed by Regional Governments): upgrading and/or modernisation works and/or local strengthening and evaluation of interventions to reduce hazard (in conformity with applicable regulations), independent of requests to proceed with maintenance or other works.
New Construction	Prohibited	New construction is not permitted.

5.1.2.1.4 – 4th Hypothesis: Prohibited Intervention (Objective 4)

The choice of this objective is subject to the following guidelines:

Construction	Intervention Type	Description
Existing	Relocation	No interventions of any kind may be made to existing buildings as relocation is mandatory.
New Construction	Prohibited	New construction is not permitted.

For historical centres, together with the above guidelines for the category of Developed Areas (recent or consolidated), the opportunity to introduce a final implementation plan, which provides for interventions of conservation and reuse, compatible with the new conditions of risk assessed, must be evaluated during the development of the IZP.

5.2 Undeveloped Areas (With or Without Plans for Development)

5.2.1 Mandatory In-Depth Analyses (Undeveloped Areas (With or Without Plans for Development)

Undeveloped Areas (with plans for development) and **Undeveloped Areas (with no plans for development)**, located within AZ_{LQ} are governed by a regime of total limitation on any form of development until such time as the studies necessary to identify SZ_{LQ} and RZ_{LQ} have been completed.

Admissible actions in these areas include the design of open spaces, without construction, serving the functions and activities of adjacent settled and urbanised areas or designed to increase the offering of urban parks, public spaces and private landscaping.

Therefore, in the absence of in-depth analysis the following guideline applies:

Construction	Intervention Type	Description
Existing	Limited	Excluding regular maintenance, hygiene-health related upgrades, or other mandatory sector-specific interventions, all other types of intervention must provide seismic upgrading and/or retrofitting and evaluation of interventions to reduce hazard (conforming to current regulations).
New Construction	Prohibited	New construction is not permitted.

5.2.2 Limited Intervention

Undeveloped Areas (with plans for development) and **Undeveloped Areas (with no plans for development)** located within SZ_{LQ} are subject to the following guideline:

Construction	Intervention Type	Description
Existing	Limited	Excluding regular maintenance, hygiene-health related upgrades, or other mandatory sector-specific interventions, all other types of intervention must provide seismic upgrading and/or retrofitting and evaluation of interventions to reduce hazard (conforming to current regulations).
New Construction	Limited	New construction is allowed with mandatory interventions to reduce hazard (in conformity with applicable regulations).

5.3 Infrastructure Program

Infrastructures, works connected to infrastructural systems and, more in general, planned *lifelines* must be relocated. If pre-existing or impossible to relocate, a specific program must be developed beforehand, in this case as part of the *Instability-prone Zones Program*. They are subject to inspections, specific investigations and interventions with the purpose of minimising risk.

6 GUIDELINES FOR POST-EARTHQUAKE RECONSTRUCTION ZONES

In a post-earthquake reconstruction area, the more onerous condition of damaged structures and the necessity to provide plans and regulations specific to the entire area subject to seismic activity, must be added to the guidelines described above.

Therefore, the first of the previous categories of urban areas (Developed Areas – recent or consolidated) must be integrated with a classification of buildings (minimum unit of intervention) based on levels of damage. A condensed outline of this classification can be found in **Appendix B1**.

6.1 Developed Areas

6.1.1 Mandatory In-Depth Analyses (Developed Areas)

In **Developed Areas (recent or consolidated)**, in the case of AZ_{LQ}, the following guidelines are defined for reconstruction or restoration in the absence of in-depth analysis:

Construction	Intervention Type	Description
Damage (light, medium-severe, very heavy)	Limited	Any intervention must include (as per the periods of time defined by Regional Governments) upgrading and/or modernisation works and/or local strengthening and the evaluation of eventual interventions to reduce hazard (in conformity with applicable regulations).

6.1.2 Instability-prone Zones Program

As already planned for SZ_{LQ} and RZ_{LQ}, in **Developed Areas (recent or consolidated)**, the following indications must be added.

In the absence of an IZP the following guideline applies:

Construction	Intervention Type	Description
Damage (light, medium-severe, very heavy)	Limited	Any intervention must include (as per the periods of time defined by Regional Governments) upgrading and/or modernisation works and/or local strengthening and the evaluation of eventual interventions to reduce hazard (in conformity with applicable regulations).

6.1.3 Objective Choice of the IZP

The IZP must progressively evaluate the possibility to adopt one of the following objectives in relation to damaged buildings:

- Limited Intervention (Objective 1)
- Mandatory or Limited Intervention (Objective 2)
- Mandatory Intervention (Objective 3)

The respective guidelines for each of these objectives are listed below.

6.1.3.1 – 1st Hypothesis: Limited Intervention (Objective 1)

The choice of this objective is subject to the following guidelines:

In RZ_{LQ} e SZ_{LQ}

Construction	Intervention Type	Description
Damage (light, medium-severe, very heavy)	Limited	Any other type of intervention must include (as per the periods of time defined by Regional Governments) upgrading and/or modernisation works and/or local strengthening and the evaluation of eventual interventions to reduce hazard (in conformity with applicable regulations).

6.1.3.2 – 2nd Hypothesis: Mandatory or Limited Intervention (Objective 2)

The choice of this objective is subject to the following guidelines:

In RZ_{LQ}

Construction	Intervention Type	Description
Damage (light, medium-severe, very heavy)	Mandatory	Relocation is not mandatory, but preferred. Mandatory interventions (within the periods of time imposed by Regional Governments): upgrading and/or modernisation works and/or local strengthening and evaluation of interventions to reduce hazard (in conformity with applicable regulations), independent of requests to proceed with maintenance or other works.

In SZ_{LQ}

Construction	Intervention Type	Description
Damage (light, medium-severe)	Limited	Any other type of intervention must include (as per the periods of time defined by Regional Governments) upgrading and/or modernisation works and/or local strengthening and the evaluation of eventual interventions to reduce hazard (in conformity with applicable regulations).
Damage (very heavy)	Mandatory	Relocation is not mandatory, but preferred. Mandatory interventions (within the periods of time imposed by Regional Governments): upgrading and/or modernisation works and/or local strengthening and evaluation of interventions to reduce hazard (in conformity with applicable regulations), independent of requests to proceed with maintenance or other works.

6.1.3.3 – 3rd Hypothesis: Mandatory Intervention (Objective 3)

The choice of this objective is subject to the following guidelines:

In SZ_{LQ} and RZ_{LQ}

Construction	Intervention Type	Description
Damage (light, medium-severe, very heavy)	Mandatory	Relocation is not mandatory, but preferred. Mandatory interventions (within the periods of time imposed by Regional Governments): upgrading and/or modernisation works and/or local strengthening and evaluation of interventions to reduce hazard (in conformity with applicable regulations), independent of requests to proceed with maintenance or other works.

Appendix B3 contains a collection of slides summarising the different land use guidelines.

7 THE ROLES OF PUBLIC INSTITUTIONS

The roles of public institutions can be summarised as follows:

State Government:

- Formulation of definitions, guidelines and general criteria for Regional Governments and Local Authorities;
- Determination of financial resources;
- Establishment of general technical criteria for defining AZ_{LQ}, SZ_{LQ}, RZ_{LQ};
- Definition of general land use planning criteria in AZ_{LQ}, SZ_{LQ} ,RZ_{LQ};
- Proposal and implementation of updates to the GSM (SM Working Group, 2015);
- Definition of methods and operative tools for the evaluation of areas subject to liquefaction identified in SM1 studies.

Regions and Autonomous Provinces:

- Adoption of general criteria established by State Government and approved by the Conference of the Regions and Autonomous Provinces;
- Formulation of additional specific criteria in relation to regional peculiarities;
- Examination and proposal of integrations and observations and/or approval of studies for liquefaction areas already defined within the regional territory, in coordination with State Government (Level 1 SM);
- Promoting and coordinating studies to define new active and capable faults within the regional territory to be transmitted to State Government (Level 3 SM);
- Mapping AZ_{LQ}, SZ_{LQ} and RZ_{LQ} (Level 1 and 3 SM) ;
- Requesting Local Authorities to inform and notify citizens of the location of AZ_{LQ}, SZ_{LQ} and RZ_{LQ} and the specific criteria for land use inside these zones.

Local Entities:

- Adopting the specific criteria formulated by the Regional Governments and Autonomous Provinces;
- Regulating land use inside AZ_{LQ}, SZ_{LQ} and RZ_{LQ};
- Preparing Programs for areas affected by liquefaction;
- Working with the Regions and Autonomous Provinces to inform citizens about the identification of AZ_{LQ}, SZ_{LQ} and RZ_{LQ} and specific land use criteria inside these areas.

APPENDIX A1
METHODS FOR CALCULATING M_W WHEN EVALUATING SUSCEPTIBILITY TO LIQUEFACTION

In the text (paragraph 2.1), when dealing with the issue of defining the intensity and duration of shaking necessary for the activation, having verified the necessary conditions, of phenomena of liquefaction, attention was drawn to the existence of classic methods for calculating the magnitude Mw to be used to evaluate susceptibility to liquefaction.

This Appendix describes these methods, highlighting for each the inherent criticalities of the method. The Appendix concludes with an original and innovative method based on the direct use of the macroseismic observations of past earthquakes in the area of study (seismic history of the site) and which constitute the majority of information available about the seismic nature of the Italian territory.

It must be noted that the methods contained in this Appendix are to be intended solely as operative proposals. It is also held that each Regional Government should adopt the method that best suits the geological, seismotectonical and seismological specificities of its specific territory.

As part of the study of liquefaction, Mw (moment magnitude) is a value tied to the physical process of an earthquake (duration) and the number of cycles of loading and unloading of deposits affected by seismic waves. It is thus preferable to choose a reference magnitude very close to the area of study.

Among the classical alternative methods of calculating Mw to evaluate the susceptibility to liquefaction, each with its own advantages and disadvantages, mention is made here of:

- Maximum magnitude from the DBMI11 catalogue;
- Criteria of magnitude-distance *cut-off*;
- Maximum magnitude of seismogenetic zones and disaggregation (GSM, 2008).

The maximum magnitude of a historic catalogue also means that the choice is completely deterministic. The majority of the magnitudes, listed in catalogues, are derived from empirical conversions Imcs-M and may thus present uncertainties typical of these transformations.

The magnitude, defined using criteria of magnitude-distance *cut-off* also involves a deterministic choice. However, the curves are constructed using data from historic earthquakes accompanied by uncertainties about their epicentre and effective scale.

The magnitude deriving from disaggregation is tied to a probabilistic study, but, owing to how they are constructed, Italian seismogenetic zones (very large) may be scarcely representative of the study area.

Maximum Magnitude (Mw_{max}) from the DBMI11 Catalogue[6]

The DBMI11 catalogue contains data of 1,681 earthquakes with their related Mw from the CPTI11 catalogue (Rovida et al., 2011), and in particular:

6 At the date of publication of these guidelines, a new version of the Macroseismic Data Base (DBMI15) and of the Parametric Catalog (CPTI15) are available. The methodological aspects, however, remain valid and therefore it was considered appropriate not to modify the original text approved by the Technical Commission.

a) 1,484 earthquakes whose data were utilised to determine the parameters listed in CPTI11;

b) 197 Etna earthquakes whose data were utilised to determine the parameters listed in CPTI11, as they relative parameters were taken directly from the Catalogo Macrosismico dei Terremoti Etnei (CMTE; http://www.ct.ingv.it/macro/etna/html_index.php).

The construction of DBMI11 is based on data from studies available through 2007:

- DBMI04 (Stucchi et al., 2007);
- CFTI4med (Guidoboni et al., 2007);
- Historic-macroseismic studies and macroseismic surveys by INGV authors;
- Catalogo Macrosismico dei Terremoti Etnei (CMTE);
- Historic-macroseismic studies published by other authors;
- Selection of data from the INGV macroseismic bulletin.

The following page can be consulted: *http://emidius.mi.ingv.it/DBMI11/* .

Criteria for the Magnitude-Distance *cut-off*

The distance beyond which phenomena of liquefaction in all likelihood do not occur may be defined by plotting the distance from the epicentre to the area of study (R) and the magnitude (Mw).

Existing literature offers many relations describing these "limit" curves known as *cut-off* curves. The most commonly utilised are those of Seed *et alii* (1984), Ambraseys (1988) and Galli (2000). Based on these curves it is possible to empirically determine the reference magnitude for the methods of estimating liquefaction. One example may be described by analysing the data in the table constructed based on the ratio from Seed *et alii* (1984). This table shows that, when the earthquake considered has a value of M=5, in order that the area of study fall under the conditions outlined in paragraph 2.1.1, it must be located at no more than 15 km from the epicentre.

The Tables below present the three relations mentioned above:

- Empirical relation from Seed *et alii* (1984) - $\log_{10} R=0.463^{*} Mw -1.14$

DISTANCE R (Km)	Mw
15	5
25	5.5
43	6
74	6.5
126	7
215	7.5
366	8

- Empirical relation from Ambraseys (1988) - $Mw = 4.64+2.65*10-3*R+0.99* \log_{10}R$

DISTANCE R (Km)	Mw
2	5
7,5	5.5
30	6
60	6.5
150	7
200	7.5
300	8

- Empirical relation from Galli (2000) (only data referred to the Italian territory) - $Me \approx Mw= 2.75+2.0*\log_{10}R$

DISTANCE R (Km)	Mw
15	5
24	5.5
45	6
75	6.5
120	7

Maximum Magnitude (Mw_{max}) of Seismogenetic Zones and Disaggregation (GSM, 2008)

The following paragraph describes a simple method, utilised for example by the Region of Lombardy, following the earthquakes of 2012[7], to estimate the value of Mw to be considered in evaluations linked to the verification of liquefaction for the area or micro-zone of study:

- Consideration of seismogenetic zoning (SZ9; INGV, 2009), according to which seismicity is distributed in 36 seismogenetic zones, each with its own maximum magnitude value Mw_{max}.
- For sites located in one of the 36 seismogenetic zones, Mw is assumed as the value of maximum magnitude Mw_{max} **(Table A3.1)**, associated with each zone.
- As shown in **Table A3.1**, all sites located in the 36 seismogenetic zones have a value of $Mw_{max}>5$ and thus all sites respect the condition outlined in paragraph 2.1.
- For sites not located in a seismogenetic zone, it is necessary to calculate the minimum distances (Ri) from adjacent seismogenetic zones (i) and verify for each whether the magnitude of the seismogenetic zone considered (M) is inferior or superior to the magnitude provided by the relation $Ms_i=1+3\log(Ri)$. In the event that at least one Ms_i, calculated for the adjacent seismogenetic zones, is inferior to the Mi of the zone for which Ms_i was calculated, the highest magnitude value Mw is to be assumed among those applicable to the adjacent seismogenetic zones (Mi=Mw); if, instead, all of the Ms_i are superior to the Mi, Mw is to be calculated using the method of disaggregation.

7 CNR-IDPA - Acquisition and elaboration of geological, geotechnical and geophysical data for the seismic characterisation of part of the territory of Lombardy situated in the Pilot Area of the GeoMol Project – "Spazio Alpino" European Program, 2015.

The method of disaggregation (or deaggregation) of seismic hazard consents an evaluation of the contributions of diverse seismic sources to the hazard present in a given area (Spallarossa and Barani, 2007). The most common form of disaggregation is two-dimensional in magnitude and distance (M-R), which permits the definition of the contribution from seismogenetic sources at a distance R capable of generating earthquakes of magnitude M. Given that maps of seismic hazard are developed in terms of the average of the distribution of hazard values obtained using diverse logical trees, disaggregation is conducted by adopting as input the models and values of parameters situated along only one branch of the logical tree. They correspond with the values of hazard closest to the average. The result is provided for 9 periods of return: 30, 50, 72, 100, 140, 200, 475, 1,000 and 2,500 years.

SZ NAME	SZ NUMBER	Mw_{MAX}
Alban Hills, Etna	922, 936	5.45
Ischia-Vesuvius	928	5.91
Other zones	901, 902, 903, 904, 907, 908, 909, 911, 912, 913, 914, 916, 917, 920, 921, 926, 932, 933, 934	6.14
Central-Marche/Abruzzo, Apennines Umbria, Nice, Sanremo	918, 919, 910	6.37
Eastern Friuli-Veneto, Garda-Verona, Garfagnana-Mugello, Ionian Calabria	905, 906, 915, 930	6.60
Molise-Gargano, Ofanto, Otranto Canal	924, 925, 931	6.83
Abruzzo Apennines, Sannio – Irpinia-Basilicata	923, 927	7.06
Tyrrhenian Calabria, Iblei	929, 935	7.29

Table A1.1 → Representation of Seismogenetic Zones and their related Mw_{max}.

It is possible to obtain average and modal values of M and R following the disaggregation of the peak values of horizontal acceleration in rigid soil (ag) with a return time in the order of 10% in 50 years (Spallarossa and Barani, 2007), or with other return times as a function of the other objectives of evaluation. The Table Comuni_MR found on the CD-ROM attached to the GSM (2008) lists the average and modal values for each Italian town, attributing maximum values to points on the chart that fall inside municipal territories, or values of points on the grid closest to municipal boundaries.

Critical Elements of the Three Methods

The magnitude estimated using historic data (thus derived from observed/reconstructed macroseismic intensity) offer notable margins of uncertainty; it would be opportune to also consider data related to more recent earthquakes than those in the DBMI11 catalogue (instrumental catalogues, i.e. ISIDe – Italian Seismological Instrumental and parametric Data-base).

Naturally, the values of Mw listed in the catalogue can be utilised only when the location of the epicentre of the event is not excessively distant (≈10 km) from the area of study.

In any case, the results obtained using this methodology should be considered indicative and reutilised in a magnitude-distance *cut-off* analysis.

The catalogues do not always contain the areas of study (i.e. areas that are too small, or whose current names do not correspond with those of the past).
The magnitude-distance criteria, other than being affected by the uncertainty of the value Mw offered by historic data, present notable uncertainties owing also to the formulas of estimating the attenuation using distance (see the comparison between the 3 tables).
The Mw estimated in SZ9 zonation and disaggregation is affected by the uncertainty of the zonation itself (and the location of the seismogenetic structures); given the vastness of SZ9 zones, in some sectors of the Peninsula, Mw may be overestimated; on the contrary, for territories not included in SZ9 zonation (i.e. many coastal areas), the estimates of Mw using disaggregation may lead to an underestimation. What is more, among the results of the analyses of disaggregation there is a general trend to utilise those with an average value though without any formal technical-scientific justification for this choice.

Original Methodology for the Calculation of Magnitude for the Verification of Conditions for Liquefaction[8]

The possibility that a particular seismic event is able to give rise to phenomena of liquefaction depends on the intensity and duration of the expected shaking.
The methodologies known to literature and incorporated in technical, scientific and normative documents (in Italy the AGI Regulations) consider these aspects, defining a threshold magnitude (typically M=5), beyond which it is considered (together with other conditions) necessary to undertake further analyses to evaluate liquefaction. The mentioned documents do not specify how the threshold magnitude is identified, and there is no indication of the distance from the event to which the threshold magnitude refers. Also, there is no expression of the relationship between the threshold magnitude and the value of the PGA used in the majority of methodologies for calculating the risk of liquefaction.
The determination of the intensity and duration of expected seismic movement begins with an analysis of seismic risk conducted using probabilistic models, focused on determining the level of likelihood associated with the diverse possible movements expected, beginning with data relative to past seismic events and other data (seismogenetic zones, relations of attenuation, etc.). A proposal is made here to use a methodology of this type, though based on the direct use of macroseismic observations relative to earthquakes that have affected the study area in the past (seismic history of the site) and which constitute the majority of information available on seismic activity across Italy.
With respect to the usual approaches (Cornell-McGuire), the results of the methodology proposed here present the following fundamental aspects, and overcome the critical issues expressed above:

- they identify a threshold magnitude linked to the distance from the epicentre of a recent seismic event and the area of study;
- they maintain a direct link with the observations effectively utilised for their determination, allowing at the same time the correct management of uncertainties inherent to this data, which is coherent with the discrete and ordinal character of the macroseismic information used in the analysis;

8 Original contribution by Dario Albarello, University of Siena.

- they closely link the values of Mw and the PGA (parameters that permit calculations of the safety factor or index of liquefaction using simplified methods) which must refer, to respect the physical nature of the problem, to the same seismic event.

The proposed methodology utilises the implementation of the SASHA code (D'Amico and Albarello, 2008) that, in its most recent version, is able to carry out a specific "disaggregation analysis" focused on identifying past seismic events most representative of local hazard (Albarello, 2012). For each municipal capital, the code provides values of macroseismic intensity characterised by a fixed return time over a fixed exposure period (I_{rif}). They also identify those historic events that have made the greatest contribution to the definition of this level of hazard. Finally, from among these values a selection is made of the event that has made the greatest contribution for its intensity I_{rif}, indicating the macroseismic magnitude and the distance from the epicentre as listed in the catalogue of referred to.

The methodology consists of 4 phases:

1. identification of the reference intensity (I_{rif}) for the site (for example characterised by a return time of less than 10% in 50 years) using a statistic/probabilistic method developed specifically to manage macroseismic data affected by uncertainty and incomplete catalogues.
2. identification of past seismic events that have affected the study site (and their distance) and which have contributed to local seismic hazard producing effects at least equal to I_{rif}.
3. assignment to each of these events of a probability that the event was effectively felt on the site with an intensity of at least I_{rif}. This latter phase permits the consideration of the uncertainties tied to the evaluation of movements when they have been inferred indirectly (from epicentre data or sensations from nearby sites).
4. identification of the reference event as that characterised by the maximum values of probability defined under point 3 (considering that with the highest magnitude Mw as having the same probability) and in any case characterised by the values of magnitude and distance from the epicentre R compatible with the relation expressed by Galli (2000) as follows:

$$\mathbf{Mw > 2.75 + 2.0 * \log_{10} R}$$

DISTANCE R (Km)	Mw
15	5
24	5.5
45	6
75	6.5
120	7

Table A1.2 → **Relation between the distance from the epicentre R and the minimum magnitude Mw necessary to provoke phenomena of liquefaction.**

For the definition of a given municipal territory as potentially subject to liquefaction (in terms of triggering conditions and excluding the possible presence of predisposing factors) **two conditions are proposed that constitute, when both are verified, the condition by which the study site can be considered potentially subject to dynamic liquefaction:**

1. a value of I_{rif} that is at least equal to VII MCS; this choice is dictated by the consideration that in the numerous laws of I_MCS-PGA conversion, the degree of VII MCS corresponds with approximately 0.1 g; furthermore, it is possible to observe that effects of liquefaction among those observed in the natural environment in occasion of events with this intensity are present only from the VII degree on the EMS98 scale.
2. the presence on the list of events contributing to I_{rif} of at least one event with Mw and distance R (km) compatible with the relation expressed by Galli (2000) mentioned above.

Table A1.3 → **Data from the site in Pontremoli.**

LAT	LON	I_{RIF}	SITE						
44.3768	9.8822	7	PONTREMOLI						
N	YEAR	MONTH	DAY	LAT_EPI	LON_EPI	Mw	Imax	DIST	PROB
10	1117	1	3	45.31	11.02	6.69	9.5	137	0.20
151	1438	6	11	44.84	10.24	5.57	8	59	0.01
190	1481	5	7	44.27	10.13	5.55	8	23	0.20
21	1501	6	5	44.52	10.84	5.98	9	78	0.05
259	1545	6	9	44.47	9.83	5.25	7.5	12	0.50
613	1767	1	21	44.13	10.12	5.35	7	33	0.03
829	1828	10	9	44.82	9.05	5.76	8	83	0.01
842	1831	9	11	44.75	10.54	5.54	7.5	67	0.01
853	1832	3	13	44.77	10.49	5.53	7.5	65	0.01
860	1834	2	14	44.43	9.85	5.83	9	7	1.00
879	1837	4	11	44.18	10.18	5.81	9	33	0.27
1088	1878	9	10	44.22	10.04	5.06	6.5	22	0.02
1429	1902	8	4	44.20	10.20	5.14	7	32	0.01
1803	1920	9	7	44.19	10.28	6.48	10	38	0.50
1812	1921	5	7	44.38	9.88	4.73	6	0	1.00
2039	1940	1	24	44.47	10.10	5.03	0	20	0.02

One example of this type of analysis is presented **(Tables A1.3** and **A1.4)** for two sites in Tuscany: Pontremoli and Castiglione della Pescaia. Pontremoli is characterised by a value of I_{rif} equal to VII MCS, while in Castiglione della Pescaia I_{rif} is equal to VI MCS. For both sites information is provided about the epicentres of events contributing to I_{rif} (year, month, day, latitude, longitude, Mw, I0, R distance from the epicentre of the study site), with an estimate of associated probabilities.
The information contained in the tables can be used to determine the thresholds of I_MCS (Mw)-Distance, useful for evaluating the hazard of liquefaction in the two areas.
Thus, for the two sites:

- Pontremoli passes the condition. In fact I_{rif} = VII MCS, the events of 1481, 1545, 1834 and 1878 have a value of Mw and R within the relation expressed by Galli (2000).
- Castiglione della Pescaia does not pass. In fact I_{rif} = VI MCS and no event features a paring of Mw and R within the relation expressed by Galli (2000).

Finally, it is possible to associate a value of Mw with the event representative of the risk of liquefaction equal to that for the event with the greatest probability that it was effectively felt on the site, with an intensity of at least I_{rif} by choosing, in the event of equal values, that with the greatest intensity. In the case of Pontremoli, the event of 1834 (Mw=5.83) has the greatest probability of occurrence. The choice of the event (and thus Mw) will involve this latter.

Table A1.4 → Data from the site in Castiglione della Pescaia.

LAT	LON	I_{RIF}	SITE						
42.7622	10.88	6	CASTIGLION DELLA PESCAIA						
N	YEAR	MONTH	DAY	LAT_EPI	LON_EPI	Mw	Imax	DIST	PROB
49	1276	5	22	42.721	12.091	5.57	8	99	0.02
54	1279	4	30	43.093	12.872	6.31	9	166	0.10
66	1298	12	1	42.575	12.902	6.20	9.5	167	0.05
82	1328	12	1	42.856	13.018	6.38	10	175	0.11
98	1352	12	25	43.469	12.127	6.44	9	128	0.41
119	1389	10	18	43.527	12.299	5.99	9	143	0.04
140	1414	8	7	43.271	11.118	5.61	7.5	60	0.16
165	1458	4	26	43.463	12.236	5.78	8.5	135	0.01
256	1542	6	13	44.006	11.385	5.94	9	144	0.03
260	1545	11	16	43.067	11.643	5.35	7.5	71	0.02
274	1558	4	13	43.457	11.564	5.82	8.5	95	0.09
302	1584	9	10	43.862	11.992	5.80	9	152	0.01
315	1599	11	6	42.724	13.021	5.99	9	175	0.01
385	1661	3	22	44.021	11.898	6.09	9	162	0.03
442	1695	6	11	42.613	12.110	5.67	8.5	102	0.03
462	1703	1	14	42.708	13.071	6.74	11	179	0.39
510	1724	12	11	43.206	11.008	5.14	7	50	0.02
552	1741	4	24	43.425	13.005	6.21	9	188	0.03
569	1747	4	17	43.204	12.769	5.94	9	161	0.01
578	1751	7	27	43.225	12.739	6.25	10	160	0.09
620	1768	10	19	43.939	11.901	5.87	9	155	0.01
671	1781	6	3	43.597	12.512	6.42	10	162	0.18
718	1789	9	30	43.510	12.217	5.84	9	137	0.02
744	1799	7	28	43.193	13.151	6.13	9	191	0.01
847	1832	1	13	42.980	12.605	6.33	10	143	0.21
914	1846	8	14	43.470	10.562	5.91	9	83	0.22
1031	1871	7	29	43.301	10.619	5.16	7.5	64	0.01
1574	1909	8	25	43.133	11.200	5.17	0	49	0.03
1672	1914	10	27	43.911	10.598	5.76	7	130	0.01
1742	1917	4	26	43.467	12.129	5.89	9.5	128	0.04
1769	1918	11	10	43.917	11.933	5.88	9	154	0.01
1780	1919	9	10	42.793	11.788	5.32	7.5	74	0.01
1803	1920	9	7	44.185	10.278	6.48	10	166	0.21
2914	1997	9	26	43.014	12.853	6.01	8.5	163	0.02

Maps of the national territory and the list of Municipalities where thresholds 1 and 2 have been verified and where, as a consequence, there exists the condition of susceptibility to liquefaction with respect to Mw and the distance from the epicentre of the seismic event, accompany this document as supplementary material, and can be found at the following link:

http://www.protezionecivile.gov.it/resources/cms/documents/Allegati_MetAlbarello.zip

APPENDIX A2
METHODS FOR MITIGATING RISKS CAUSED BY LIQUEFACTION

The damage to structures caused by phenomena of liquefaction can be reduced by adopting three categories of countermeasures (JGS, 1998):

1) declaration that the area is not suitable for construction and relocation of all existing or planned structures;

2) mitigation of hazard through the implementation of interventions focused on improving the characteristics of potentially liquefiable deposits;

3) reduction of the vulnerability of manmade constructions through interventions designed to strengthen structures and prevent damages.

In occasion of earthquakes with very high levels of shaking (Kobe, Japan) it has been observed that truly effective results have been achieved through the parallel realisation of the countermeasures described in points 2) and 3) above, more so than point 1).

The countermeasures of point 2) are aimed at improving the characteristics of the soil, in order to increase its resistance to liquefaction, by working with factors such as:

- increasing soil density **(Fig. A2.1)**;
- soil compaction **(Fig. A2.2)**;
- reduction of the level of saturation, with an increase in effective pressures **(Fig. A2.3)**;
- dissipation and control of water pressure **(Fig. A2.4)**;
- control of shear deformation and an excess of neutral pressure **(Fig.A2.5)**.

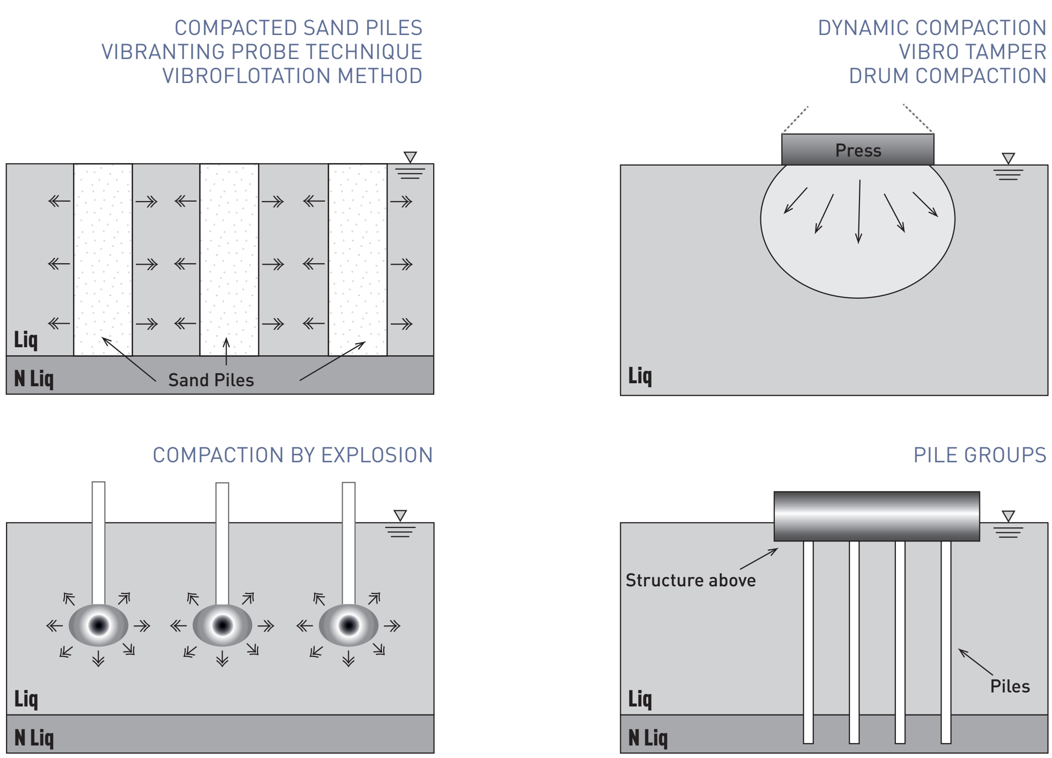


Figure A2.1 → Category 2 countermeasures: increasing the density of liquefiable soils.

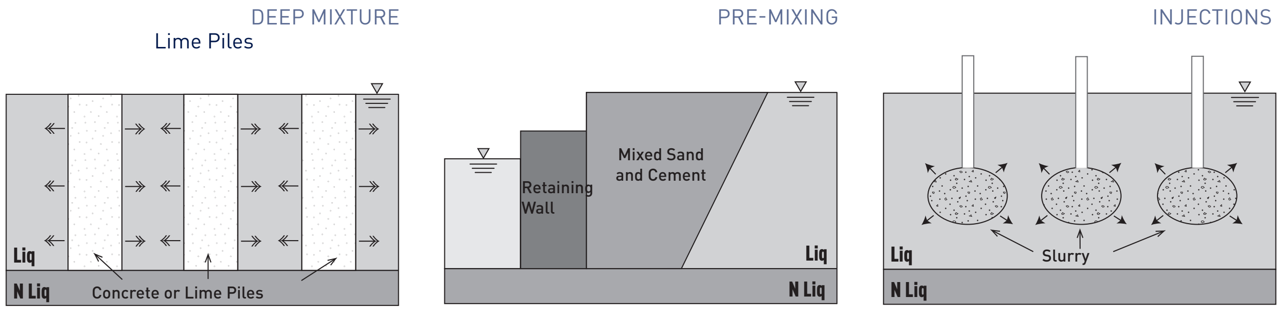


Figure A2.2 → Category 2 countermeasures: compaction of liquefiable soils.

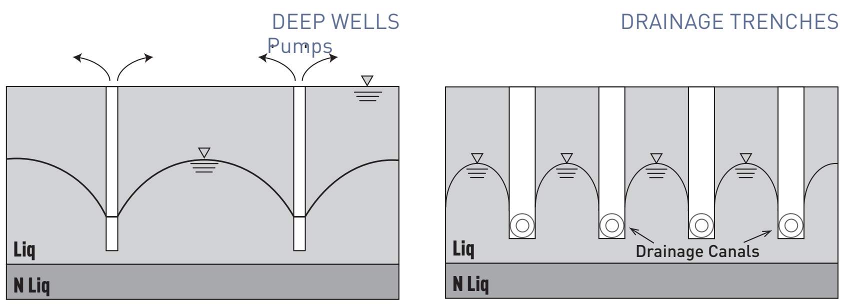


Figure A2.3 → Category 2 countermeasures: reduction of the level of saturation and increase in the effective strengths of liquefiable soils.

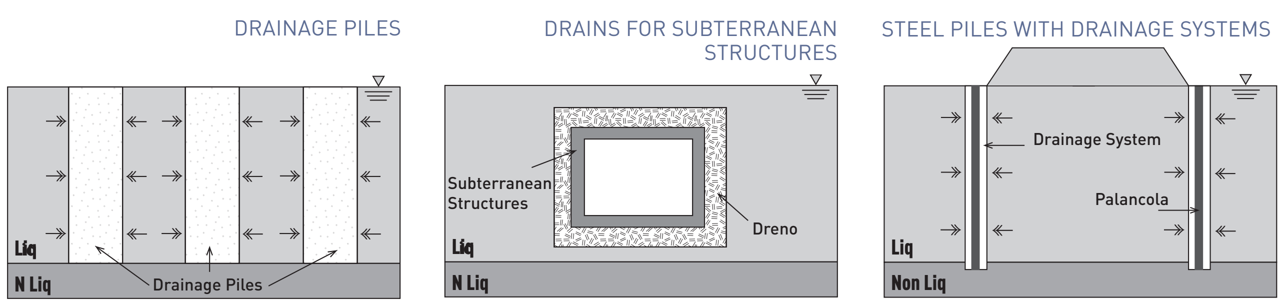


Figure A2.4 → Category 2 countermeasures: dissipation and control of neutral pressure.

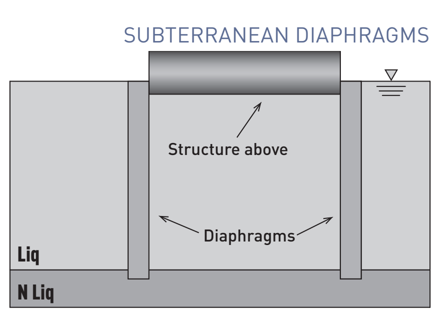


Figure A2.5 → Category 2 countermeasures: control of shear deformation and interception of excess water pressure.

APPENDIX A3
METHODS OF INTERVENTION DURING THE EARLY PHASES OF AN EMERGENCY

The earthquakes of 20 and 29 May 2012 affected a vast area of the Emilia-Romagna Plain and the Oltrepò Mantovano, generating phenomena of liquefaction, in a particular manner, in correspondence with abandoned historic water courses.

These phenomena were of particular relevance above all in two inhabited centres in the western part of the province of Ferrara: the hamlet of S. Carlo, part of the town of S. Agostino, and the town of Mirabello. They caused the temporary inaccessibility to a number of buildings, road closures and interruptions to services following the rupture of underground utilities. For this reason, the Region of Emilia-Romagna's Servizio Geologico, Sismico e dei Suoli and the Civil Protection Department commissioned a team of specialists to evaluate the post-seismic geotechnical risks in areas most affected by the extensive and significant phenomena of liquefaction: S. Carlo di Sant'Agostino and Mirabello.

The immediately observed effects of liquefaction were:

- the ejection of water and sand in the form of a small volcano (*sand boils*);
- lateral movements of earth (*lateral spreading*) on rises;
- local uniform and/or differentiated settlements of structures, in some cases with rotation.

The following section summarises the first interventions made in S. Carlo.

A series of site visits were made on the 24 and 25 May to examine the diverse geotechnical effects caused by the earthquake.

Much of the inhabited area of San Carlo di Sant'Agostino presented important ejections of sand, both through ruptures in the soil and in water wells. In particular, were the sand was unable to find a direct route, in this case the wells, it was present in copious ejections of a mixture of water and soil:

- sand boils outside buildings;
- buckling of pavements in basement and ground floor levels of buildings, with the transportation for the most part of the most superficial foundation soils (generally of a finer grain) and the liquefaction of part of the layer of soil below (larger grain);
- cracking.

In correspondence with historic riverbanks, morphologically higher than the average grade level, the ejections of sand, both inside and outside buildings, were accompanied by widespread phenomena of local and global instability, with often serious consequences for the stability of buildings.

In flat areas and at the summits of rises, corresponding with elevations in the system of canals-banks, deep fractures formed, in some cases characterised by the exclusively horizontal dislocations measuring tens of centimetres, and in other cases vertical dislocations measuring hundreds of centimetres. Neighbouring buildings suffered consequent rotations and collapses.

Figure A3.1 illustrates the sites in the historic centre of S. Carlo di Sant'Agostino and its surroundings where the aforementioned phenomena of localised and linear liquefaction were observed.

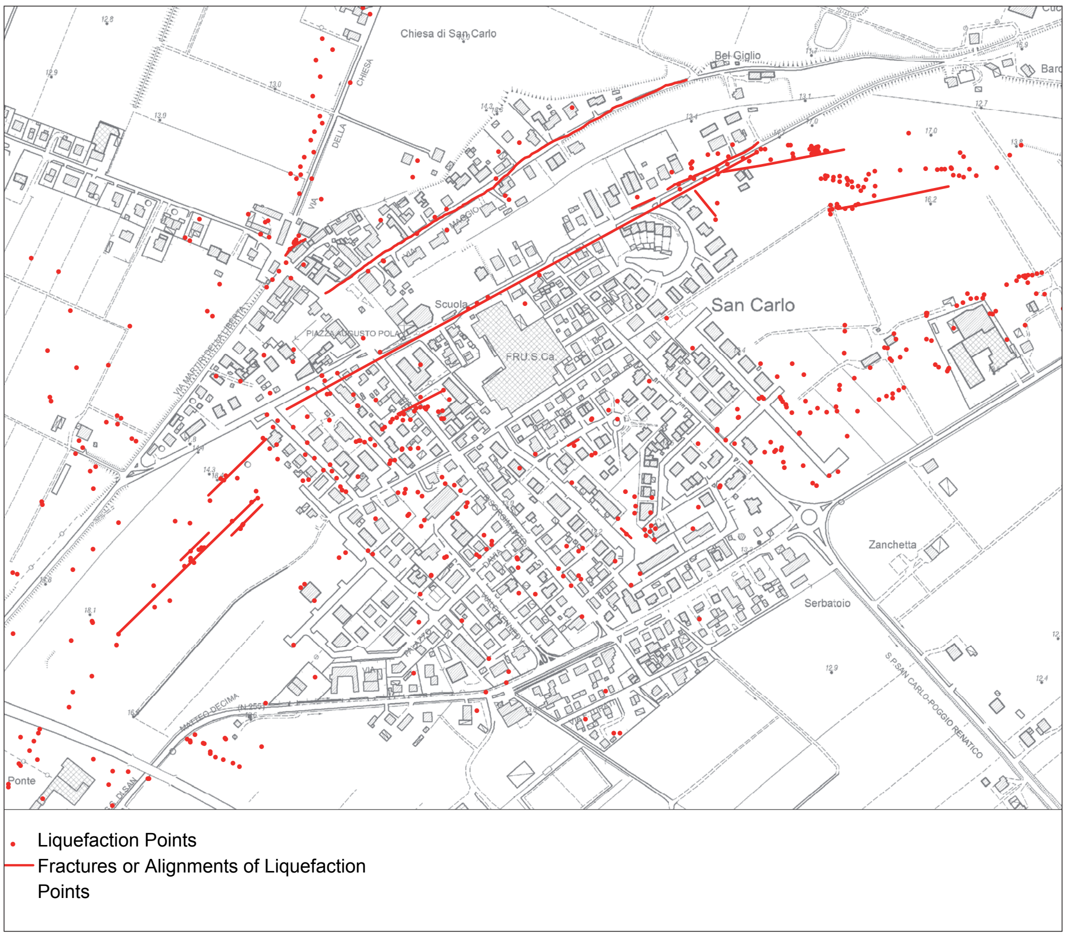


Figure A3.1 → Effects of Liquefaction observed in S. Carlo di Sant'Agostino.

not to scale

Following the first site visits and based on the evidence present on the surface and the qualitative observation of foundation soils and a comparison between these qualitative observations and previous geological and geomorphological information, given the impossibility to exclude deferred post-seismic effects over time (measured in weeks), the prudent decision was made to declare particular areas temporarily inaccessible due to geotechnical hazards (the red zone).

To better identify the areas affected by elevated levels of geotechnical hazard, and in which to concentrate future studies and verifications, a map of geotechnical damages to buildings was drawn up. This map classifies buildings based on the results of site visits by teams of engineers sent to record damages, accompanied by geotechnical engineers specialised in liquefaction.

Buildings were classified as follows **(Figure A3.2)**:

- inaccessible owing to serious structural damages tied to liquefaction (in red);
- building to be revisited or partially inaccessible owing to minor structural damages tied to liquefaction (in orange);
- accessible, though declared inaccessible as a temporary precaution for geotechnical reasons (in green).

Following this mapping, the decision was made to initiate a programme of cognitive investigations to understand the nature and mechanical properties of different terrains through a campaign of in situ tests **(Figure A3.3)** to:

- define the lithostratigraphic structure of different soils;
- install piezometers to monitor variations in the water table during the transitory post-seismic phase;
- undertake downhole geotechnical and geophysical tests and obtain undisturbed samples for successive laboratory testing.

Figure A3.2 → Building damage classes in areas with geotechnical problems.

not to scale

A topographic system of monitoring was also installed, using high precision levelling, to measure eventual post-seismic shifts in buildings classified "green" **(Figure A3.4)**. Geodetic monitoring activities were implemented to observe eventual vertical movements in different inhabited buildings, for the most part residential, and to a lesser degree used for commercial or religious purposes.

Finally, all of the surveys and investigations pursued the objective of verifying the state of foundation soils, following the effects of liquefaction, and identifying the ends of the transitory post-seismic period.

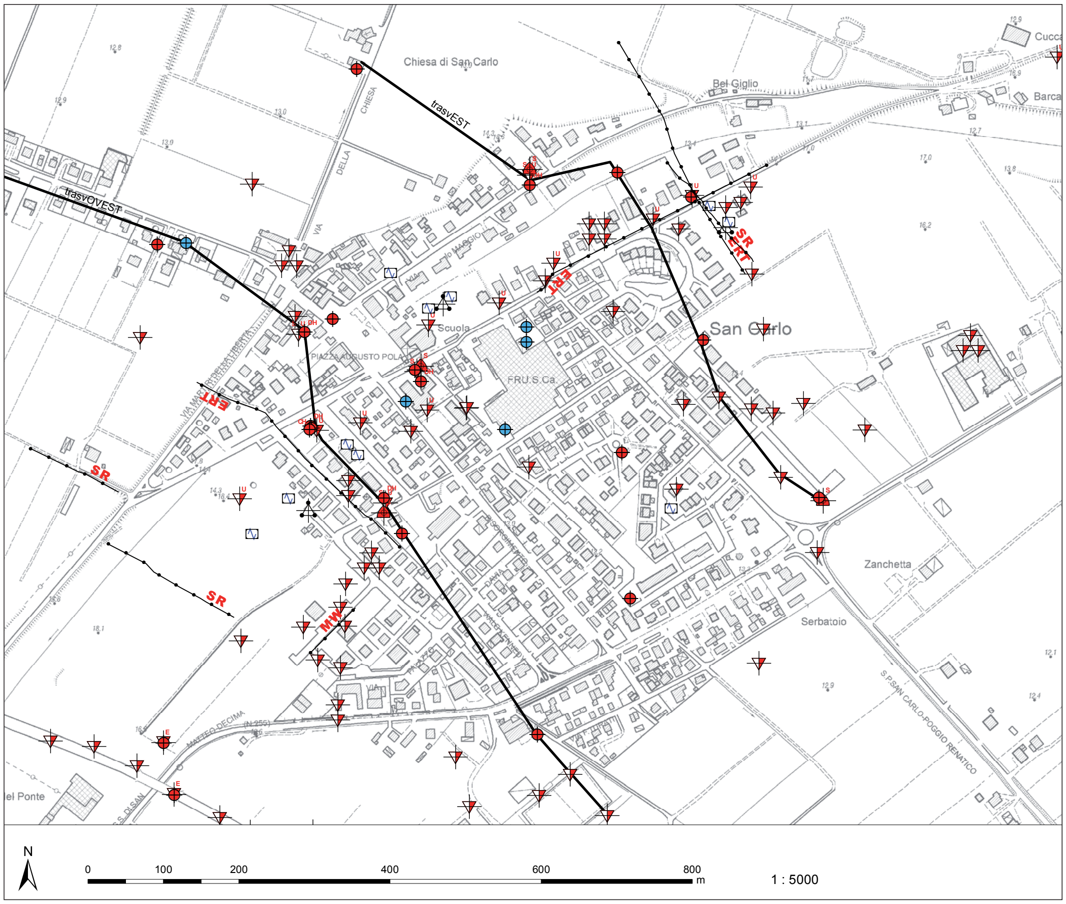
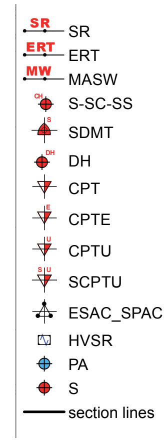


Figure A3.3 → **Map of in-situ investigations in the centre of S. Carlo di S. Agostino.**



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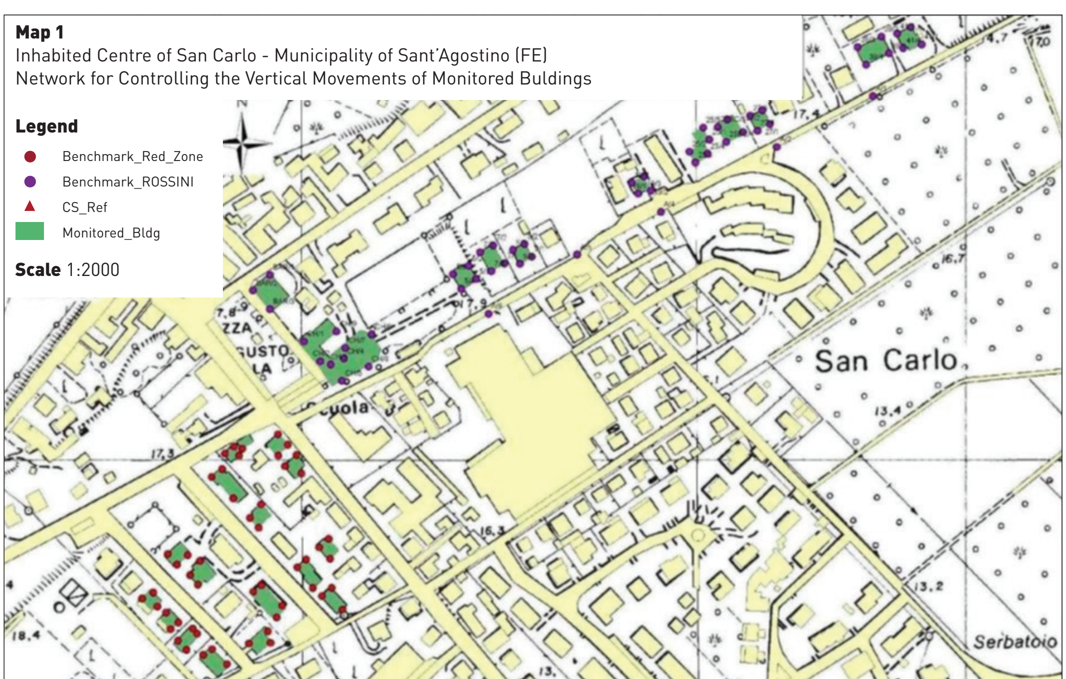


Figure A3.4 → **Location of the topographic monitoring network.**

APPENDIX B1
OUTLINE OF THE INSTABILITY-PRONE ZONES PROGRAM

General Purpose

The general purpose of the Instability-prone Zones Program is to reduce the eventual effects of

- liquefactions;
- (...)

Subject and Specific Purpose

1. The SZ or RZ of affected municipalities are to be the subject of a specific Program that verifies and pursues [*selection based on the chosen objective*]:
   - ☐ relocation of all strategic functions and the identification of other locations or new realisations in areas outside the SZ and RZ;
   - ☐ relocation of important buildings, as defined in Decree n. 3685/2003, issued by the Head of the Italian Civil Protection Department;
   - ☐ relocation of residential functions;
   - ☐ change of the use for Undeveloped Areas (with plans for development), to services and other functions, without construction;
   - ☐ interventions of antiseismic retrofitting or limited rehabilitation of existing buildings;
   - ☐ priorities of intervention among SZ and RZ.
2. This program identifies financial incentives, urban planning incentives and bonuses designed to favour the rapid and complete implementation of interventions of relocation with the aim of achieving the highest levels of seismic safety and the qualification of urban areas by interested private subjects.
3. The program includes an analysis of financial requirements for its realisation.
4. The program identifies interventions that may be in accordance with applicable general urban planning instruments or require changes:
   - when the realisation of new primarily residential or productive settlements is indispensable, the program calls for the contextual realisation and completion of related territorial services and mobility infrastructures;
   - when these forecasts are not present in current urban planning regulations, they must be identified adjacent to and in continuity with the existing urban fabric.
5. Sites for the transfer of delocalised buildings and functions must privilege the reuse of existing buildings and abandoned areas in developed areas or those with certain plans for development.
6. The program can also be carried out through specific publicly developed implementation plans, where necessary, to be approved through the Planning Agreement pursuant to Art. 34 of Decree n. 267/2000 [Italian National Building Code].

Implementation Tools. Final Implementation Plans

1. The program identifies areas subject subejct to specific final implementation plans.
2. The final implementation plans as per article 1, discipline urban transformation to be made within SZ and RZ to achieve the general and specific objectives indicated in article 2, which include:
   - building renovations, for the seismic upgrading of buildings hosting compatible functions;
   - urban rehabilitation works with a particular focus on increasing the system of escape routes and their redundancy;
   - changes to building uses hosting strategic functions and the object of relocation.
3. The plans identify the Minimum Unit of Intervention, as defined by the Regions, requiring a modifications to urban planning instruments. They establish structural systems, plans and volumetric forms and the most appropriate design characteristics for conserving urban fabrics, together with any other detailed regulation necessary to proceed with the realisation planned interventions. Incentives are offered to the constitution of consortia and agreements between the owners of properties involved in unified interventions, favouring the synergy between the public and private sectors and improving project schedules.
4. The plan identifies the limits for allowable classes of use and intervention types referred to technical norms, in addition to identifying:
   - portions of urban zones intersected by SZ and RZ to be included in the plan in relation to the unity and coherence of the urban context and as a function of the Minimum Unit of Intervention;
   - suitable areas for the relocation of urban functions.
5. With the aim of ensuring the feasibility of an intervention, the decision to adopt a plan must be accompanied by a dedicated report on the full involvement of all interested private subjects, made possible by the stipulation of compensating agreements demonstrating the availability of the necessary financial resources for the implementation of planned interventions.
6. To ensure the full involvement of all interested private subjects, the contents of the plan may be the object of preliminary agreements with private subjects.
7. The framework of understanding and environmental evaluations related to the plan must be presented in accordance with SEA (Strategic Environmental Assessment) legislation, considering seismic microzonation and with particular reference to urbanised areas and those pre-selected for new settlements.

APPENDIX B2
SUMMARY CLASSIFICATION CHARTS

Each urban planning indication in Tab. B1 (represented here) is associated with one or more indications relative to the typology of intervention for Existing Construction or New Construction, as per **Table B2**.

URBAN CATEGORY		DEVELOPED AREAS (RECENT OR CONSOLIDATED)	UNDEVELOPED AREAS (WITH PLANS FOR DEVELOPMENT)	UNDEVELOPED AREAS (WITH NO PLANS FOR DEVELOPMENT)	INFRASTRUCTURES
Liquefaction Zones	AZ_{LQ}	Mandatory In-Depth Analyses (5.1.1)	Mandatory In-Depth Analyses (5.2.1)		Infrastructures Program (5.3)
	SZ_{LQ}	Instability-prone Zones Program (5.1.2)	Limited Intervention (5.2.2)		
	RZ_{LQ}				

Table B2.1→ Urban Planning Indications.

URBAN CATEGORY		DEVELOPED AREAS (RECENT OR CONSOLIDATED)	UNDEVELOPED AREAS (WITH PLANS FOR DEVELOPMENT)	UNDEVELOPED AREAS (WITH NO PLANS FOR DEVELOPMENT)	INFRASTRUCTURES
Liquefaction Zones	AZ_{LQ}	EL – NI	EL – NI		Infrastructure Program
	SZ_{LQ}	EL – NI (EL – NL)	EL – NL		
	RZ_{LQ}	(EO – NL) (EO – NI) (ED – NI)			

Table B2.2 → Typologies of Intervention for Existing and New Buildings

Sigla	Construction	Intervention Type	Description
EL	Existing	Limited	Excluding regular maintenance, hygiene-health related upgrades, or other mandatory sector-specific interventions, all other types of intervention must provide seismic upgrading and/or retrofittingand/or local strengthening and evaluation of interventions to reduce hazard (conforming to current regulations).
EM	Existing	Mandatory	Relocation is not mandatory, but preferred. Mandatory interventions (within the periods of time imposed by Regional Governments): upgrading and/or modernisation works and/or local strenghtening and evaluation of interventions to reduce hazard (in conformity with applicable regulations), independent of requests to proceed with maintenance or other works.
ER	Existing	Relocation	No interventions of any kind may be made to existing buildings as relocation is mandatory.
NL	New Construction	Limited	New construction is allowed with an evaluation of interventions designed to reduce hazard (in conformity with applicable regulations).
NI	New Construction	Prohibited	New construction is not permitted.

URBAN PLANNING CATEGORIES		DEVELOPED AREAS (RECENT OR CONSOLIDATED)
Liquefaction Zones	AZ_{LQ}	LL – ML – VL
	SZ_{LQ}	LL-ML-VL (LL-ML-VL) (LL-ML-VM) (LM-MM-VM)
	RZ_{LQ}	(LL – ML – VL) (LM – MM – VM)

Legenda Table B2.3 → Indications on the type of interventions for existing and damaged buildings.

Sigla	Construction	Intervention Type	Description
LL ML VL	Damaged (light, medium-severe, very heavy)	Limited	Any intervention must include (as per the periods of time defined by Regional Governments) upgrading and/or retrofitting works and/or local strengthening and the evaluation of eventual interventions to reduce hazard (in conformity with applicable regulations).
LM MM VM	Damaged (light, medium-severe, very heavy)	Mandatory	Relocation is not mandatory, but preferred. Mandatory interventions (within the periods of time imposed by Regional Governments): upgrading and/or retrofitting works and/or local strenghtening and evaluation of interventions to reduce hazard (in conformity with applicable regulations), independent of requests to proceed with maintenance or other works.

Abbreviations relative to the buildings listed above refer to a possible classification based on levels of damage. Classification systems can use an evaluation of the damage level starting from the inspections after an earthquake **(Fig. B2.1)**.

Description of damage levels based on the EMS 98 scale obtained from the conversion of detected damage during inspections after an earthquake:

- **D1 negligible to slight damage** (no structural damage, slight non-structural damage) Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases.
- **D2 moderate damage** (slight structural damage, moderate non-structural damage) Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys.
- **D3 substantial to heavy damage** (moderate structural damage, heavy non-structural damage) Large and extensive cracks in most walls. Roof tiles detached. Chimneys fractured 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.

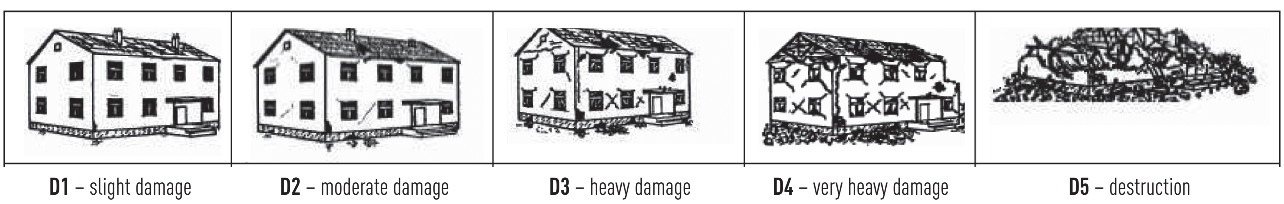
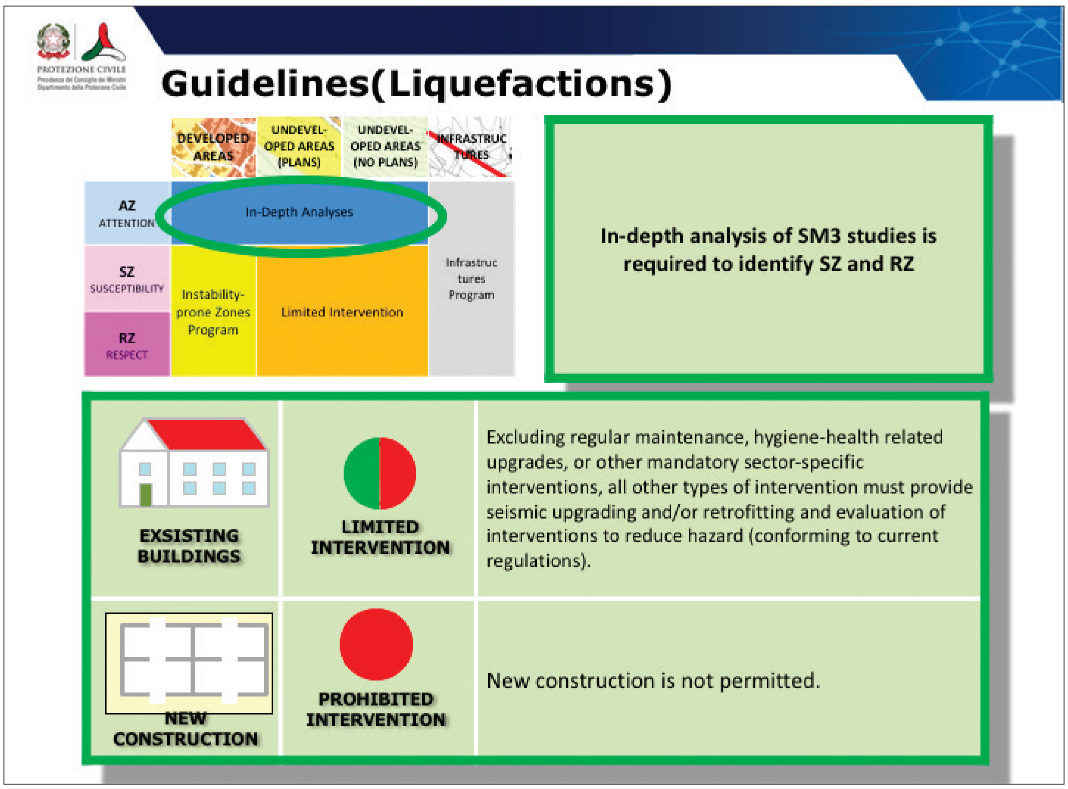
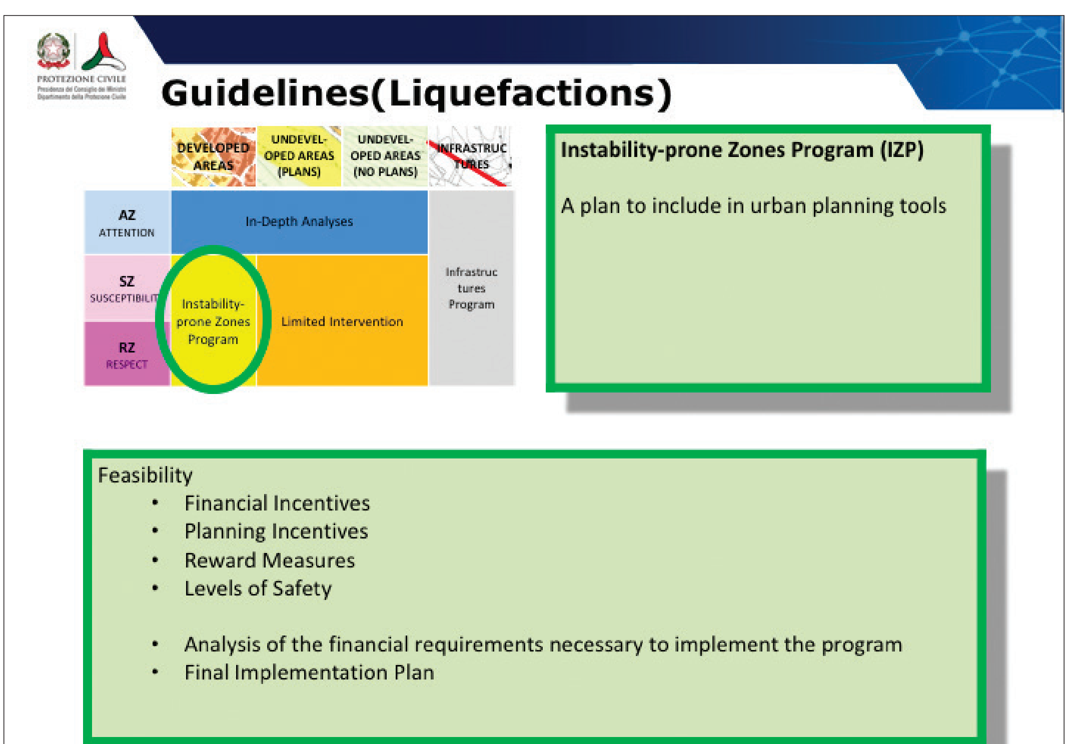


Figure B2.1 → **Definitions of Damage Levels.**

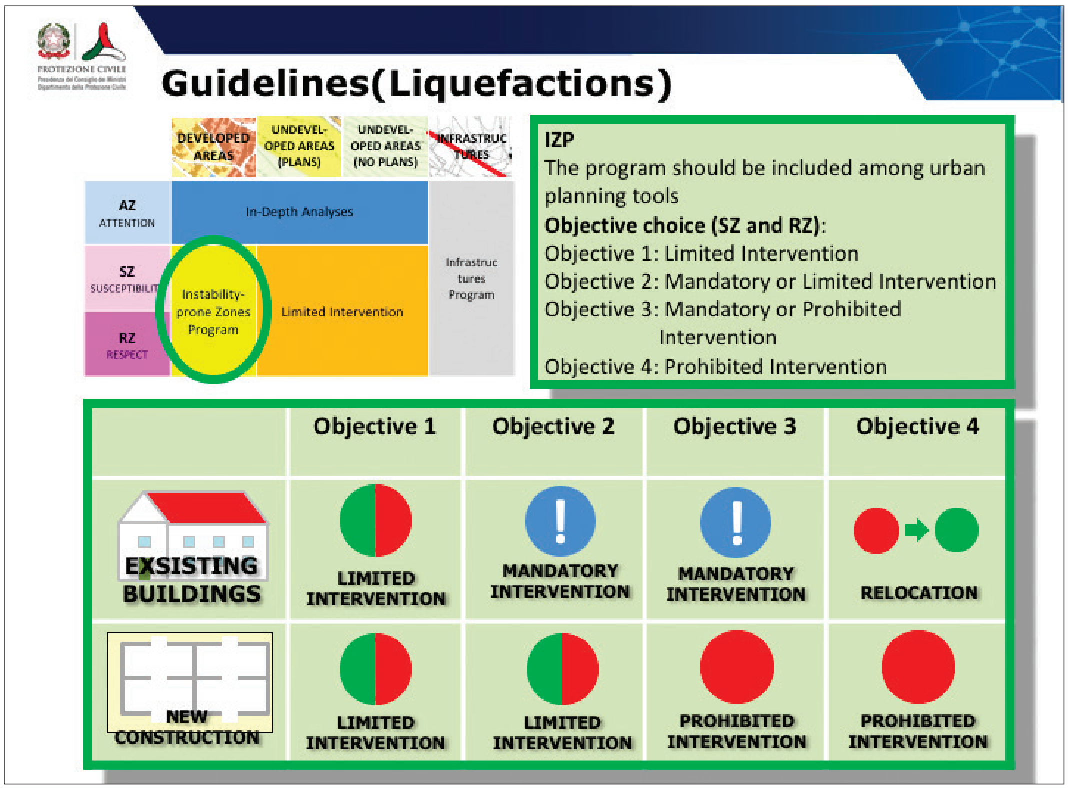
APPENDIX B3
SUMMARY OF ALLOWABLE INTERVENTIONS



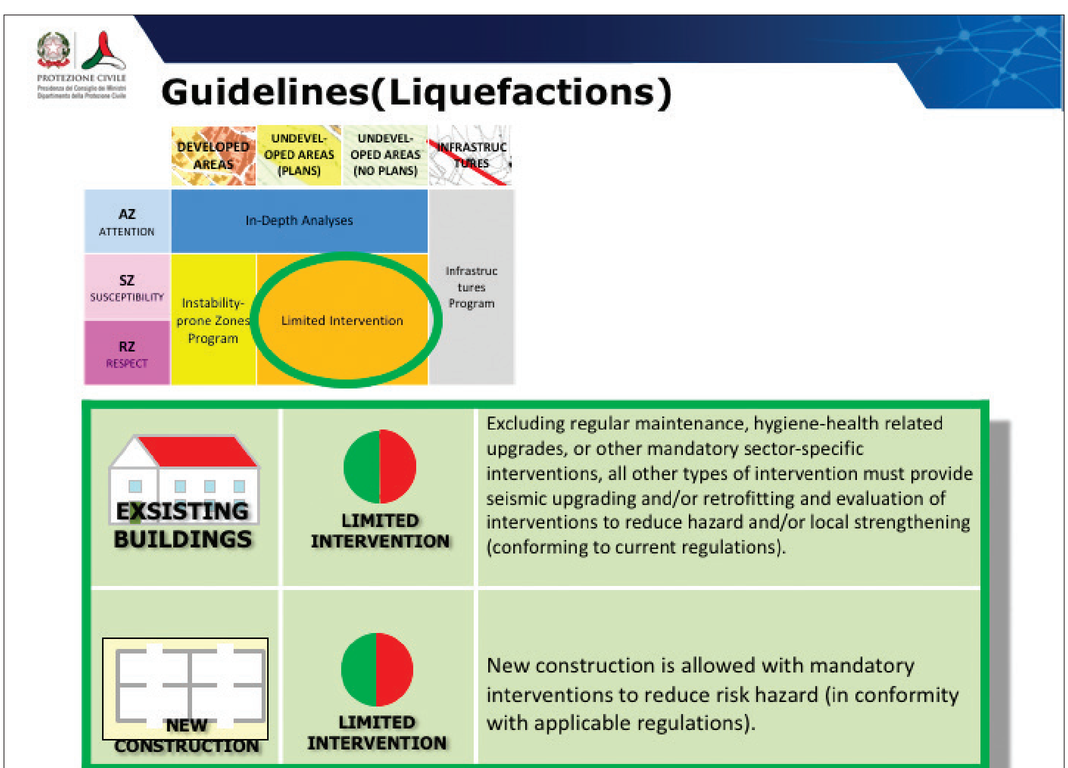
Slide 1 → **Attention Zones: Limited Intervention for existing buildings and prohibition of any new construction .**



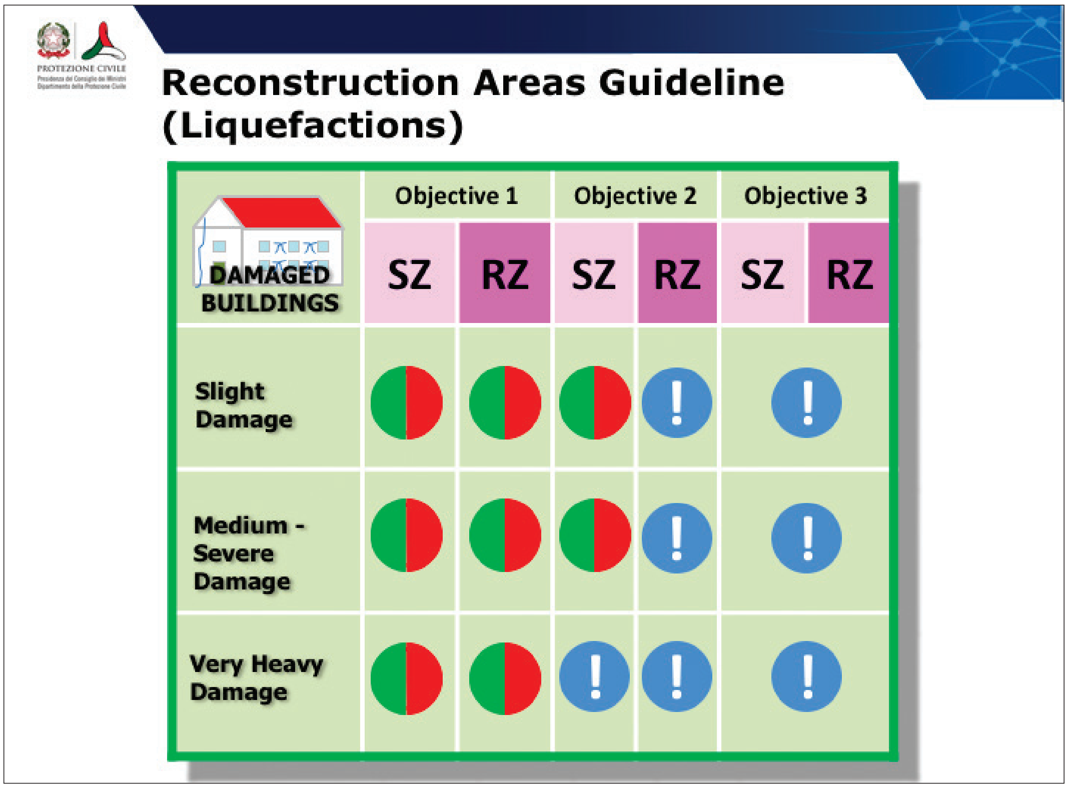
Slide 2 → **Susceptibility Zones and Respect Zones for Developed Areas: Definition of the Instability-prone Zones Program (IZP).**



Slide 3 → **Susceptibility Zones and Respect Zones for Developed Areas: IZP Objective Choice.**



Slide 4 → **Susceptibility Zones and Respect Zones for Undeveloped Arease (with or without plans for development): Mandatory Interventions for existing buildings and limited interventions new constructions.**



Slide 5 → **Reconstruction Areas Guideline, depending on the objective selected for the IZP.**

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ATTACHMENTS

National Territory Map and list of Municipalities with verified thresholds 1 and 2, defined by the Albarello method, and where the condition of susceptibility to liquefaction exists in relation to Mw and the distance from the epicentre of a seismic event.
List of attached files:

- Liquef_Alleg1_Elenco.xlsx
- Liquef_Alleg1_Dist.pdf
- Liquef_Alleg1_Magn.pdf
- Liquef_Alleg1_Risent.pdf

The attachments can be downloaded at the following link:
http://www.protezionecivile.gov.it/resources/cms/documents/Allegati_MetAlbarello.zip

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