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E DELLE PROVINCE AUTONOME

PROTEZIONE CIVILE
Presidenza del Consiglio dei Ministri
Dipartimento della Protezione Civile

Guidelines for

SEISMIC MICROZONATION

Conference of Regions
and Autonomous Provinces of Italy
Civil Protection Commission
Sub-Commission 8
Implementation of Seismic Legislation

Presidency of the Council of Ministers
of the Italian Republic
Civil Protection Department

Guidelines for

SEISMIC MICROZONATION

SM Working Group
"Guidelines for Seismic Microzonation"

Edited by *F. Bramerini, S. Castenetto, G. Naso*

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Presidency of the Council of Ministers
of the Italian Republic Civil Protection Department

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Presentation of the English edition

Following the 6 April 2009 Abruzzo Earthquake, the Italian Parliament enacted a new law aimed at stimulating the seismic risk prevention in Italy. Article 11 of Law 77/2009 allocated the funds for seismic risk prevention across Italy, amounting to 965 million Euro over a seven-year period. The funds are distributed among the Regions according to their seismic risk.
One of the qualifying aspects of the implementation of the seismic risk prevention plan is the identification of seismic microzonation (SM) in individual towns as a key tool in developing a strategy of seismic risk mitigation.
All the institutions involved have agreed on selected principles that ensure the operability and reality of the programme as financed:

- *SM studies must be incorporated within municipal planning practices and common methods and standards must be adopted for the entire national territory;*
- *territorial interventions focused on seismic risk mitigation must be coordinated, starting from a verification of the effectiveness of systems for emergency situation management.*

Current decrees governing interventions concede financial contributions to the Regions with the condition of co-financing up to a maximum of 50% of the cost of SM studies. After speaking with the Municipalities involved, the Regions must issue a dedicated legislative tool that identifies the Municipalities where these studies are deemed a priority, selected from among the 3,896 Municipalities with medium to high seismic risk (peak ground acceleration on stiff soil with 475 years return period less than 0.125g).

To implement this normative mandate, a Technical Commission (TC) for inter-institutional co-ordination was established. The Commission provides technical documents, guides and monitors activities and verifies the state of advancement of the programme across the nation. The Civil Protection Department, together with the CNR-IGAG (National Research Centre-Institute of Environmental Geology and Geo-engineering), has established a technical secretariat to manage the SM data and information to support the TC. SM studies are approved by the Regions after the evaluations made by the TC.
The reference technical document for the realisation of these studies is currently represented by these Guidelines for Seismic Microzonation, adopted by each Region in dedicated legislative measures. Hence, the Guidelines govern the realisation of all SM studies across Italy.

Chairman of the Technical Commission
for Seismic Microzonation

Mauro Dolce

Presentation

The approval of these "Guidelines for Seismic Microzonation" by the Conference of Regions and Autonomous Provinces of Italy marked the end of a painstaking project, made possible by the constant and strong synergies developed by the Civil Protection Department and the Italian Regions and Autonomous Provinces.

The results of this project represent a major step forward in terms of scientific and operational methods and instruments proposed for prevention. They also represent an advance in technical-administrative cooperation with the potential players of land management policies focused on seismic risk mitigation.

Over 100 specialists and experts contributed to this document, accepting the task with enthusiasm and spirit of service, offering their specific skills and know-how, embracing a interdisciplinary approach and establishing a dialogue with the Administrative Bodies directly concerned.

Apart from the results of the project, it is worth stressing the value of the relationship of cooperation established between the professional world, the research community and public institutions to achieve common goals.

It is our hope that this document will be followed by further and fruitful joint activities, aimed at ensuring the rapid development of the most effective, systematic and widespread policies of seismic risk mitigation across Italy.

Rome, 2008.

Deputy Minister, Presidency of the Council
of Ministers of the Italian Republic
Head of the Civil Protection Department

Guido Bertolaso

President,
Conference of the Presidents of the Regions
and Autonomous Provinces of Italy

Vasco Errani

C.N.R. (Italian National Research Council)
"GEODYNAMICS" PROJECT
MUNICIPALITY OF S. ANGELO DEI LOMBARDI PLATE 2

PRELIMINARY SEISMIC MICROZONATION

SCALE 1:5,000

a_1 Zones with active landslides (Sheet 1, 2 and 3 of the engineering-geological map) and their clearance area. Construction of buildings or structures not recommended. If these zones are to be crossed by infrastructures (roads, aqueducts, etc.), appropriate investigations shall be carried out to identify the most suitable routes and construction procedures (see report).

a_2 Zones whose geomorphology indicates very steep and occasionally abrupt slopes. Construction of buildings or structures usually not recommended and in any case subject to the provision of suitable foundations and to the application of the slope coefficient (see report).*

a_3 Zones that developed surface ruptures and dislocations following the earthquake of 23 November 1960. Construction of buildings or structures not recommended.

b_1 Zones of precarious stability (Sheet 4 and 5 of the engineering-geological map). Any project for the construction of new buildings or structures shall be based on the results of investigations aimed at assessing their stability.*

b_2 Zones whose subsoil demonstrates discernible horizontal and vertical discontinuities and possibly poor mechanical properties (successions 2, 3, 4 and 5 of the engineering-geological map). Any project for the construction of new buildings or structures or for the rehabilitation of damaged buildings or structures shall be based on studies aimed at assessing soil characteristics (mechanical properties, thickness, etc.) and at guiding the choice of suitable foundations. In particular, strict compliance with the dynamic lateral deformability requirements specified in the report is recommended.

b_3 Zones with lithological and morphological characteristics similar to zones a2 and b2, respectively. The rules for the above zones shall apply.

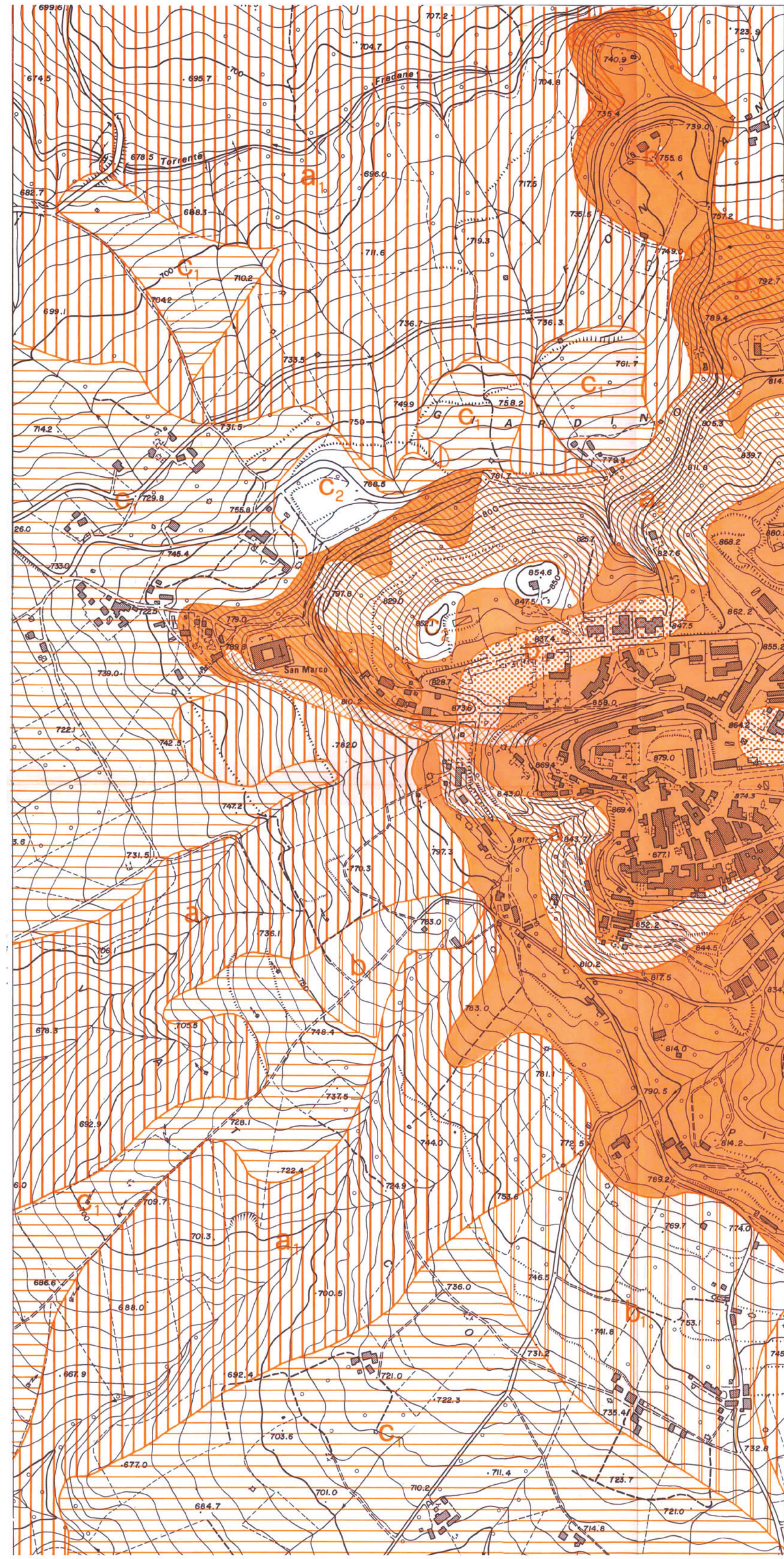
b_4 Zones whose surface soil has generally poor technical characteristics and which were particularly damaged by the earthquake of 23 November 1960, owing to local geological conditions. Pending further investigations, reconstruction is not recommended.

c_1 Generally stable zones with possible moderate instability at local level (Sheet 6 of the engineering-geological map). Rehabilitation as in the case of zones b Any project for the construction of buildings or structures must be preceded by a stabilisation project.

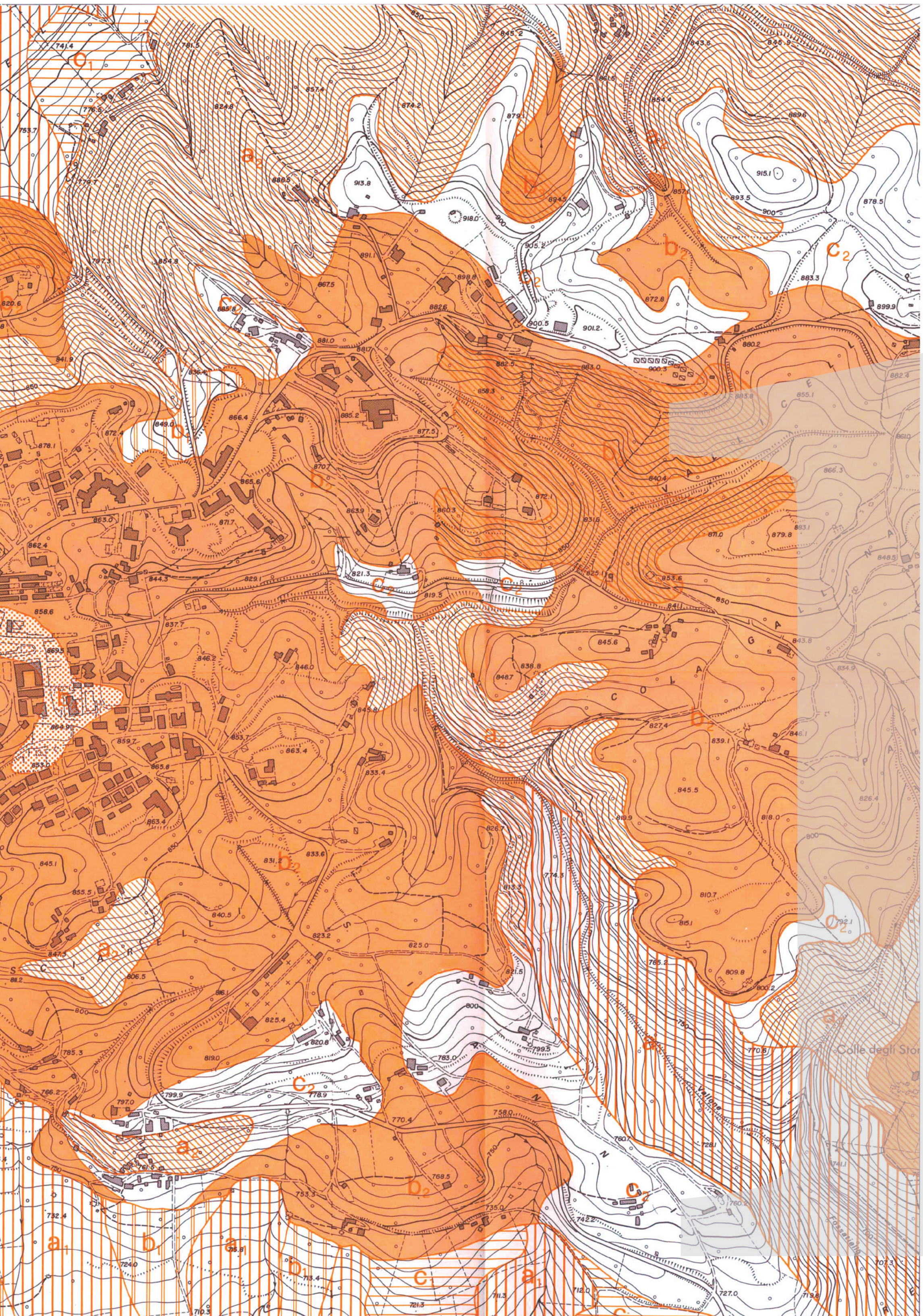
c_2 Zones with good lithological and morphological characteristics. No particular rules. However, anti-seismic criteria and the recommendations formulated in the report shall be strictly applied across the entire Municipal territory.

***Rehabilitation of buildings as per the criteria detailed in this report.**

EDITED BY
C. Bosi – A. Parducci – M. Rossi-Doria



Instructions and criteria



Preliminary seismic microzonation in the Municipality of S. Angelo dei Lombardi (Avellino), (CNR – PFG, 1984).

1.1 Introduction

Public Administrations in Italy (State, Regional and Local Governments) are responsible, among things, for the preparation of risk mitigation instruments. With the improvement of living conditions, communities have growing expectations of acceptable levels of risk. To lower these levels of risk and improve results, Administrative bodies must put in place increasingly more effective and efficient systems. These systems should continuously improve risk assessments and related mitigation measures and raise the awareness of local communities and parties (businesses, associations, etc.) of risks and the measures adopted to reduce them. Demands for risk mitigation are not expressed directly and specifically by the population. They are expressed indirectly and, often, only after events entailing losses and costs for the entire community. Therefore, these demands cannot, per se, ensure acceptable requirements, considering – among others – the general shortcomings of legislative instruments and the organisation of risk management. There is a need for new rules and guidelines governing risk management.
The management system adopted by any government body or, more generally, any organisation, reflects its objectives, instruments and approaches. Hence, the approach to risk analysis varies from body to body. One of the chief purposes of the Instructions and Criteria for risk analysis and assessment is to improve systems and processes, so as to mitigate risks and enhance safety.

These *Guidelines for Seismic Microzonation* are intended to represent the core of the seismic hazard analysis necessary for seismic risk analyses applicable to land, urban and emergency planning, as well as to technical design standards.
Seismic microzonation (SM) is defined as "the assessment of local seismic hazards by identifying the zones of a given geographic area with homogeneous seismic behaviour. In practice, SM identifies and characterises stable zones, stable zones prone to local amplification of seismic movement and zones prone to instability". The issues addressed by SM studies have been the objective of significant scientific development over the past few years, although their importance had already emerged in the past.
It has long been known that local conditions of foundation soils have a significant impact on the effects of an earthquake. As early as one century ago, in the wake of the catastrophic earthquake of Messina and Reggio Calabria (1908), the guiding criteria of the technical standards approved by Royal Decree no. 193 on 18 April 1909 banned the construction and reconstruction of buildings or structures "on soils lying over and near fractures or prone to slumping or landslides or capable of transmitting fast and abrupt vibrations and stresses to buildings, owing to their different geological composition or the different strength of their constituent parts"[1].
It is easy to understand, from this sentence alone, that the effects of an earthquake in terms of ground motion (reversible and permanent deformations strongly correlated with local soil characteristics) were already clear at this time."[1].

1 L'azione del Governo fascista per la ricostruzione delle zone danneggiate da calamità, edited by the Italian Ministry of Public Works, General Direction for Special Services (1932) .

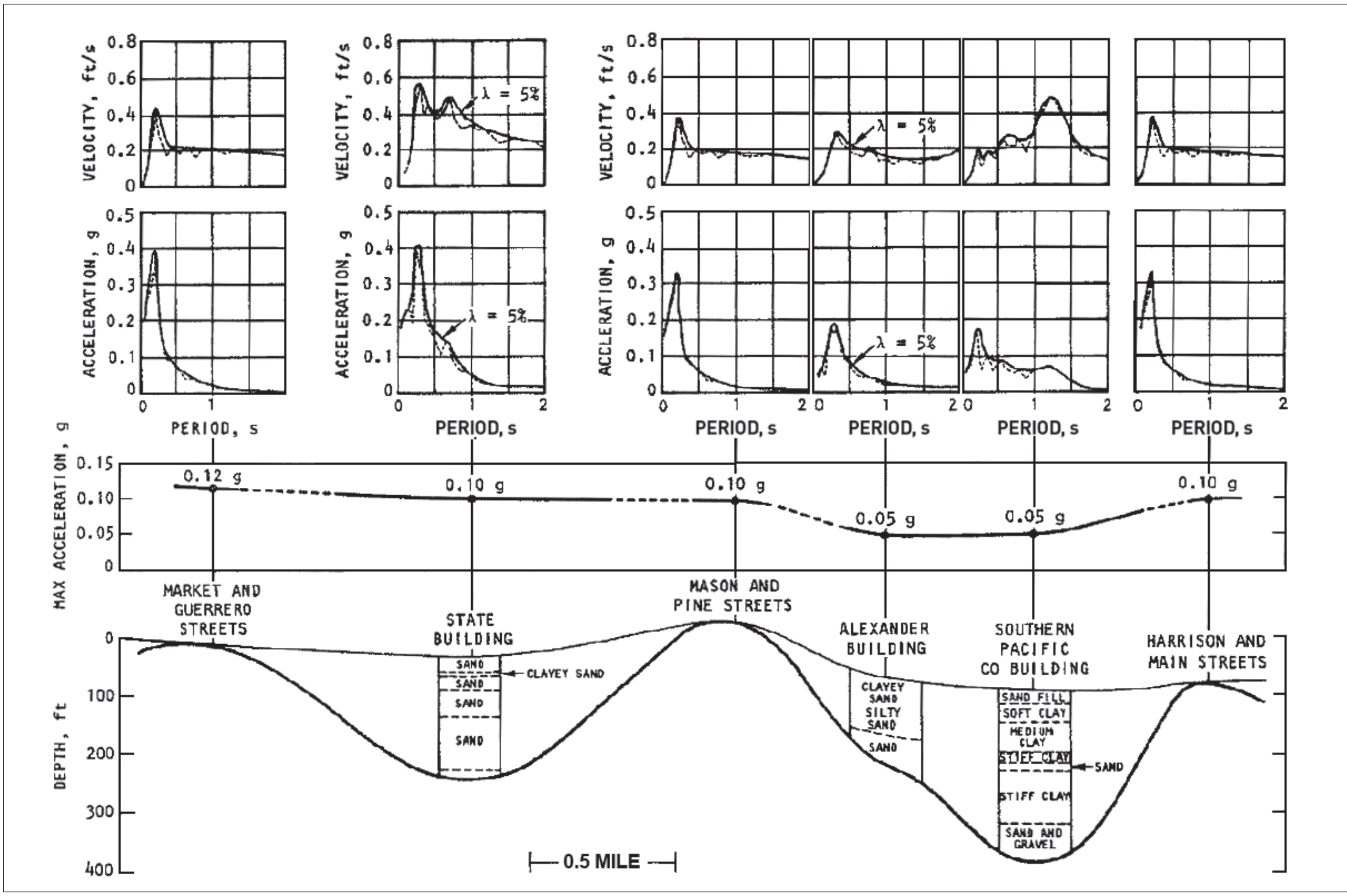


Figure 1.1-1 – Change of ground motion in a 4-mile cross-section of San Francisco during the earthquake of 1957 (Seed & Idriss, 1969).

In 1969, Seed & Idriss[2] carried out a study of the ground motion records of the 1957 San Francisco earthquake. The results clearly demonstrated that, in the same city, at a distance of only a few hundreds of metres, the same earthquake caused markedly different types of ground motion, depending upon the thickness and characteristics of shallower and softer soil layers. In the following years, further studies of ground motion records and structural models, demonstrated that the buildings investigated had been subjected to very different seismic stresses (both resultant seismic stress and frequencies), thereby explaining the varying levels of damage observed in similar structures bearing on different soils.

Since this time studies of many earthquakes (e.g. Mexico City, 1986; Kobe, 1992; Izmit, 1999) have increasingly demonstrated that local land features may significantly alter seismic action. In Italy, widely varying levels of structural damage were observed (Umbria-Marche earthquake, 1997) in similar buildings, separated by only a few hundreds metres.

2 Seed, H.B. and Idriss, I. M. (1969) – "Influence of soil conditions on ground motion during earthquakes", in *Journal of the Soil Mechanics and Foundation Division,* ASCE, vol. 95, N. SM1.

In the same area, aftershock ground motion records showed that motion amplification in a site located in a plain resting on loose soil was more than twice and much longer than that of a site bearing on solid rock.

As often happens, an understanding of the importance of a phenomenon is only gradually transposed into the construction of buildings or structures. Increases in building movement related to the nature of soils were introduced into Italian seismic legislation as far back as 1975 and, until 2003, the foundation coefficient has remained "generally equal to 1" or 1.3 in the case of "foundations on more compressible soils"[3].

Figure 1.1- 2 – Umbria-Marche earthquake, 1997. Differences in damage to neighbouring sites due to local effects. Left, Cesi Bassa (IX MCS); right, Cesi Villa (VII MCS).

In addition to amplifications to ground movement, phenomena of liquefaction, surface fault rupture and slope instability have been observed for many centuries and documented by numerous historical records.

Seismic Microzonation studies have the purpose of rationalising the knowledge of these phenomena and of providing useful data to those in charge of planning or implementing projects in a given geographic area.

The preparation of these *Guidelines for Seismic Microzonation* involved the Italian Regional Governments, the Autonomous Provinces and the Central Government ("Dipartimento della Protezione Civile – DPC", Civil Protection Department). Although organisationally cumbersome and time-consuming, this approach boasts some of the advantages typical of similar processes.

3 DM 3 March 1975, n. 39. Approvazione delle norme tecniche per le costruzioni in zone sismiche (Approval of the Building Code for Construction in Earthquake-Prone Areas).

Figure 1.1- 3 – Effects due to liquefaction (Izmit, Turkey, 1999).

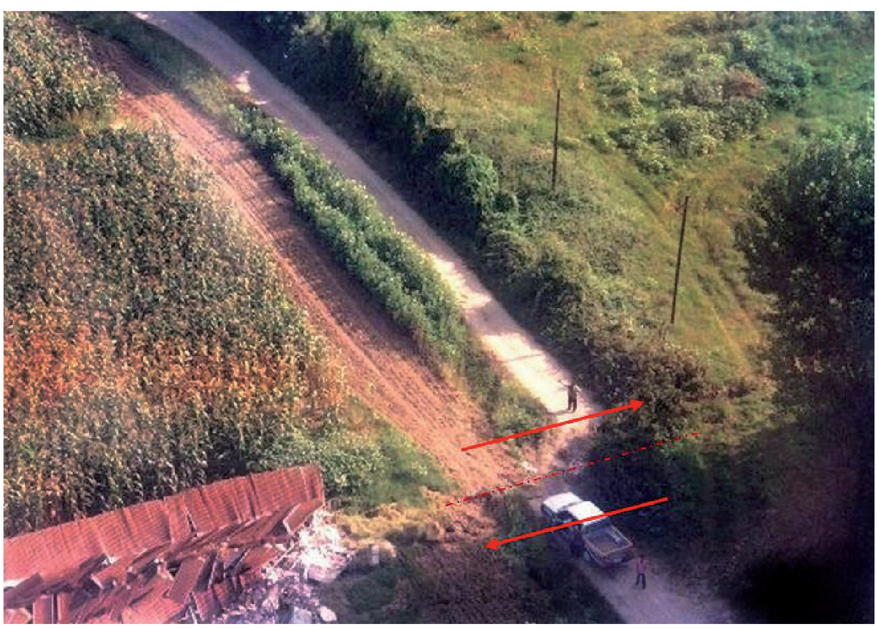


Figure 1.1-4 – Surface faulting (Izmit, Turkey, 1999).

On one hand, an ability to produce the best "deliverables" through discussions between multiple parties to redefine problems and propose new mediations and resolutions. On the other hand, decisions acquire more legitimacy, since they are not made separately by a small group, but by a plurality of parties. While they may not fully share the final decisions, they each recognise the legitimacy of the approach. Finally, this type of approach promotes dialogue and constructs relationships based on mutual trust.

The process began in early 2006, when the Civil Protection Department submitted[4] a proposal to the Civil Protection Commission of the Conference of Regions and Autonomous Provinces of Italy: es-

4 DPC, Proposal for the Institution of a Task Force to develop *Guidelines and Criteria for Seismic Microzonation* , 21 April 2006, prot. DPC/SSN/0021305.

tablishing a working group (including specialists/experts appointed by the Regions and by the Civil Protection Department) in charge of formulating the Guidelines for Se*ismic Microzonation*. The first regional experiences in microzonation acquired after various earthquakes and some pieces of regional legislation issued on these matters served as the pre-requisites for laying a common groundwork and for accommodating what had been developed and experimented by the scientific community, as well as the demands expressed in various ways by regional and local governments.

The Civil Protection Commission unanimously approved the proposal[5], establishing that the working group should work in synergy with Sub-Commission 8 on the "Implementation of Seismic Legislation", coordinated by the Umbria Regional Government. On 16 November 2006, Sub-Commission 8 defined the activities and objectives of the working group, which took over its responsibilities on 19 February 2007. The group developed a one-year working schedule, involving the setting-up of 4 Sub-Groups and the preparation of 3 interim reports to be submitted to Sub-Commission 8, 1 report to be sent to selected external parties in order to gather comments and suggestions (consultation process) and 1 final report to be submitted to the Conference of Regions and Autonomous Provinces of Italy. The Civil Protection Department provided operational and organisational support.

In October 2007, Sub-Commission 8 invited the representatives of the external parties[6] to a conference convened to mark the beginning of the consultation process. During the conference a questionnaire was circulated to collect comments and suggestions. The suggestions were transposed into this document, which was endorsed by the working group and forwarded to Sub-Commission 8 for approval by the Conference of Regions and Autonomous Provinces of Italy.

Taking into account the inputs provided by the external parties, the working group emphasised that the testing and application of the *Guidelines for Seismic Microzonation* represented an integral part of the national forecasting and prevention programs referred to in art. 4 of Law n. 225 dated 24 February 1992[7].

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5 CRP, Political-Institutional Meeting of the Civil Protection Commission 20 July 2006.

6 National Council of Geologists, National Council of Engineers, National Council of Architects, National Council of Land Surveyors, National Association of Italian Municipalities, Union of Italian Provinces, National Union of Mountain Municipalities and Communities, Italian Geotechnical Association, Italian Association of Applied and Environmental Geology, Italian National Association of Seismic Engineering, National Urban Planning Institute and Technical Forum on Land Management of the Civil Protection Commission.

7 Based on the guidelines approved by the Council of Ministers and in compliance with the criteria determined by the National Council of Civil Protection as per art. 8, the Civil Protection Department is responsible for the preparation of national forecasting and prevention programmes for various risk assumptions and national emergency relief programs, as well as plans for implementing related emergency measures (art. 4).
The SM study is typically multidisciplinary and, at all levels of investigation, requires the gathering, archiving, calculation and representation of a considerable amount of information, of a diverse nature and with diverse significance, useful to the description of an integrated model of the subsoil.
There is thus an evident need to provide tools useful to the rational and organised collection of material, in order that it be immediately available for use in SM studies. The realisation of a similar system of archiving, management and representation requires the development of clear and shared procedures and the overcoming of complex problems related not only to methods of sorting data, but also to its selection, standardisation, codification and cartographic representation. Specific standards have been drawn up to respond to these concerns.
The standards originate in post-earthquake experiments in the area of L'Aquila and have been developed based on the observations formulated by Research Institutes (CNR, ENEA, ISPRA), Universities (Basilicata, Siena, Politecnico Milano, Sapienza Roma), the Regions and Autonomous Provinces of Italy and by the TC created specifically for this purpose.
The standards pursue the following specific objectives:

- the calculation and relative representations of significant elements and issues, focusing on the simplification and synthesis of content;
- standardising the representation of different issues by all subjects involved to facilitate the reading and comparison of the results of different studies;
- guaranteeing the simplest and most flexible system of data archiving.

The standards also pursue the objective of favouring the exchange of data and facilitating their certification by the Regions. A special freeware programme (SoftMS) was developed to facilitate data input activities. Internet resources: http://www.protezionecivile.gov.it/jcms/it/commissione_opcm_3907.wp
http://www.protezionecivile.gov.it/jcms/it/view_new.wp;jsessionid=FB14B41035C08400D9541DF400615C5F?contentId=NEW39357
http://centromicrozonazionesismica.it

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SPECIFIC COOPERATION FOR THE PREPARATION OF THE INSTRUCTIONS AND CRITERIA

Francesco Fazzio	Sub-Group 3 (municipal and area-wide planning, "minimum urban structure")
Francesco Giordano	Sub-Group 1 (data processing for schedules)
Salomon Hailemikael	Sub-Group 1 (map data processing)
Cosmo Mercuri	Sub-Group 3 (municipal and area-wide planning)
Filomena Papa	Sub-Group 4 (emergency planning, scenarios)
Roberto Parotto	Sub-Group 3 (municipal and area-wide planning, minimum urban structure)
Monica Picone	Sub-Group 1 (methodologies and databases, slope instability)

PREPARATION OF THE GUIDELINES AND APPENDICES

Procedures for preparing investigations	Giuseppe Naso, Giacomo Di Pasquale
Procedures for drawing up the Investigation Map	Luca Martelli
Procedures for drawing up the map of seismically-homogenous Microzones (Level 1)	Giuseppe Naso, Gabriele Scarascia Mugnozza, Stefano Rivellino, Salomon Hailemikael
Procedures for drawing up the seismic microzonation map (Level 1)	Giuseppe Naso, Fabrizio Bramerini
Procedure for drawing up the schedules for amplification (Level 2)	Dario Albarello, Tito Sanò, Giacomo Di Pasquale, Giuseppe Naso, Antonio Lucantoni, Floriana Pergalani
Procedure for defining slope instability (Level 2)	Gabriele Scarascia Mugnozza, Monica Picone, Laura Cavalera
Procedure for assessing the probability of occurrence of liquefaction (Level 2)	Teresa Crespellani
Procedure for estimating magnitude in view of verifying instability-prone zones	Giacomo Di Pasquale, Tito Sanò
Dynamic behaviour of soils	Teresa Crespellani
Seismically-induced landslides	Roberto W. Romeo
Liquefaction hazards	Diego Lo Presti
Surface faulting	Paolo Galli
Passive measures of environmental seismic noise	Dario Albarello, Marco Mucciarelli
Strong/weak-motion study for local seismic response	Giuliano Milana, Antonella Paciello
Numerical simulations	Tito Sanò
Input motion for numerical simulations	Giuseppe Naso
Assessment of local seismic response from type of and damage to buildings surveyed after earthquakes	Agostino Goretti, Mauro Dolce
Seismic zoning and seismic classification of municipalities	Fabrizio Bramerini, Giacomo Di Pasquale
Emergency planning	Elvezio Galanti, Maria Ioannilli, Antonio Monni, Sabrina Primerano, Massimiliano Severino, Monica Sugan, Antonio Torrisi
Damage scenarios for emergency planning	Filomena Papa, Giulio Zuccaro
Modelling of damage scenario amplification effects	Fabrizio Bramerini, Giuseppe Naso
Reference schedules for lithostratigraphic effects (Level 2)	Francesco Giordano, Giacomo Di Pasquale, Tito Sanò
Reference schedules for topographic effects (Level 2)	Floriana Pergalani, Massimo Compagnoni
Technical instructions for performing geological, geophysical and geotechnical investigations, collecting related data and presenting results	edited by Maurizio Ferrini, Massimo Baglione, Vittorio D'Intinosante, Pierangelo Fabbroni (Tuscany). Referees: Arnaldo Boscherini (Umbria), Antonio Colombi (Lazio), Rossella Monaco (Molise), Francesco Ponziani (Umbria) The chapters on DMT and SDMT tests were written by D. Marchetti, S. Marchetti, P. Monaco and G. Totani.
DVD	Fabrizio Bramerini, Giacomo Di Pasquale, Giuseppe Naso

1.2 Reference Legislation

Law n. 64 from 2 February 1974, Building Code with Particular Guidelines for Earthquake-Prone Areas.

Law n. 741 from 10 December 1981, Further Regulations for the Acceleration of Procedures to Complete Public Works.

Public Works Ministerial Decree dated 11 March 1988, Technical Regulations for Soil and Rock Studies, Natural Slope and Slope Stability, General Criteria and Prescriptions for the Design and Inspection of Earthworks and Foundations.

Law n. 225 from 24 February 1992, Institution of the National Civil Protection Service

Public Works Ministerial Decree dated 16 January 1996, Technical Regulations for Construction in Earthquake-Prone Areas

Ministry of the Interior Decree dated 13 February 2001, Adoption of "General Criteria for the Organisation of Health Services during Catastrophes" (published in the Gazzetta Ufficiale n. 116 on 12 May 2001).

Legislative Decree n. 112 from 31 March 1998, Assignment of Administrative Roles and Responsibilities from the State to Regional and Local Entities, in Accordance with Chapter I of Law n. 59 from 15 March 1997.

Decree of the President of the Italian Republic n. 380 from 6 June 2001, Unified Text on Legislative Measures and Regulations Governing Construction.

Law n. 401 from 9 November 2001, Conversion into Law, with Modifications, of Bill n. 343 from 7 September 2001, Containing Urgent Measures for Ensuring the Operative Coordination of Civil Protection Structures.

Ordinance of the President of the Council of Ministers n. 3274 from 20 March 2003, Initial Elements of General Criteria for the Seismic Classification of National Territory and Technical Regulations for Construction in Earthquake-Prone Areas

Law n. 186 from 27 July 2004, Conversion into Law, with Modifications, of Bill n. 136 from 28 May 2004, "Urgent Measures for Guaranteeing the Functionality of Particular Sectors of the Public Administration. Measures for Re-determining the Legislative Delegations and Related Measures".

Directive issued by the President of the Council of Ministers on 12 October 2007, Directive of the President of the Council of Ministers for the Evaluation and Reduction of Seismic Risk to Cultural Heritage in Relation to the Building Code.

Decree of the Minister of Infrastructure from 14 January 2008, Approval of the Building Code.

1.3 Parties Involved in Seismic Microzonation Studies

Regional Government: issues specifications on how to carry out and utilise the studies.

Proposing Party: (Regional or other local government): plans and funds SM studies and assigns them to the implementing parties.

Implementing Party: (offices of the Region or other local government, professionals, engineering companies, research institutions): implements SM studies under the coordination of the proposing party.

Validating Party: (offices of the Region or other local government): ensures that the implementing party has met the specifications defined by the proposing party. This party may coincide with the proposing party, but should not coincide with the implementing party.

Designer/s[8]: works/work in accordance with general regional guidelines; responsible for project-related data, for specific investigations (if any), for comparisons with national legislation, for verifying the conformity between design conditions and the homogenous zone of reference, and motivating eventual exceptions.

One-Stop Service for Construction Activities[9]: based on regional decisions, this service ensures that submitted documents refer to SM studies.

Project Supervisor[10]: in accordance with regional decisions this figure may examine the justification of the use of SM in relation to each project and level, the correctness of documentary references, the coherence between design choices and SM.

8 Decree of the President of the Republic 380/2001, art. 64, paragraph 4: "The designer shall have direct responsibility for designing all the components of the building or structure, whatever the method used for their construction".

9 Decree of the President of the Republic 380/2001, art. 5, paragraph 1: "As part of their organisational autonomy, Municipal Governments shall establish an office called "one-stop service for construction activities". This office may be established, among others, in compliance with section V of Legislative Decree no. 267 of 18 August 2000, i.e. by merging, splitting or eliminating existing offices or bodies. This office shall handle all the relations between private individuals and the Administration and, where necessary, the other Administrations that are held to express an opinion on the construction project for which a permit or a declaration of commencement of works has been submitted". Art. 65, paragraph 4: "Upon submission of the project and of the report, the one-stop service shall provide the builder with a copy of the project and of the report, certifying the submission".

10 Decree of the President of the Republic 380/2001, art. 93, paragraph 3: "The minimum content of the project shall be determined by the competent technical office of the Region. At any rate, the project shall be exhaustive in terms of layouts, plans, maps, drawings and cross-sections and accompanied by a technical report, by a folder with the calculations of below-ground and above-ground carrying structures and by drawings of the final engineering details of the structures". Art. 94, paragraph 3: "Notwithstanding the obligation to obtain a permit for the construction project, no works shall be commenced in seismic sites (except for the low-seismicity sites specified in the decrees referred to in article 83), without obtaining a prior written authorisation from the competent technical office of the Region".

1.4 Definitions

Local (or site) effects – Effects arising from the behaviour of the soil upon a seismic event due to particular lithostratigraphic and morphological conditions, which cause local *amplification and soil instability (slope instability, liquefaction, active faults and capable faults, differential settlements, etc.).*

Exposed Elements (or Assets) – Anything that may be negatively affected by a seismic event and which are thus the object of seismic risk analyses. They can be identified through homogeneous categories and systems that may suffer losses as a result of a seismic event.
Examples of exposed categories and systems are: environment, population, economic activities, public services, cultural property, etc.

Phenomena of Soil Instability – Permanent changes to the soil, e.g. landslides, liquefaction or densification, surface faulting, etc., due to a seismic event.

Seismic Microzonation (SM) – The assessment of Local Seismic Hazard through the identification of zones with seismically homogeneous behaviour.
In practice, seismic microzonation identifies and characterises stable zones, stable zones prone to local amplification of seismic motion and zones prone to instability.

Seismic Hazard – The quantitative estimation of ground motion caused by a seismic event in a given area. Seismic hazard may be analysed using deterministic methods, by assuming a given reference earthquake, or with probabilistic methods, explicitly considering uncertainties regarding the magnitude, location and time of occurrence of the earthquake. In these Guidelines the analyses of the *Regional Seismic Hazard* have been distinguished from the analyses of the *Local Seismic Hazard*.

Regional Seismic Hazard – The component of seismic hazard resulting from the general seismological characteristics of an area (type, size and depth of seismic sources, energy and frequency of earthquakes). Regional Seismic hazard calculates (generally employing a probabilistic method) the parameter values corresponding to predetermined probabilities of exceedance in a given region and over a given period of time. These parameters (velocity, acceleration, intensity, spectral ordinates) describe the ground motion produced by the earthquake under conditions of rigid soil without morphological discontinuities (reference earthquake). The scale of study is generally regional. One of the purposes of these studies is the large-scale seismic classification of a given area for prevention activities or emergency planning. Regional Seismic hazard represents the starting point for defining the reference earthquake in view of *seismic microzonation* studies.

Local Seismic Hazard – The component of seismic resulting from specific local characteristics (lithostratigraphic and morphological, see also *local effects*). The study of local seismic hazard is conducted in detail, beginning with the results of *Regional Seismic hazard* studies (reference earthquake) and by analysing the geological, geomorphological, geotechnical and geophysical characteristics of the site. This analysis permits the definition of *local amplification* and the probability of *soil instability*. The most important deliverable produced by this type of study is the *Seismic Microzonation* Map.

Risk Reduction (or Risk Mitigation) – Actions undertaken to reduce the probabilities and/or negative consequences associated with a given risk (ISO, Guide 73:2002).

Seismic Risk – The probability that a given level of economic-social damage or loss may occur or be exceeded in a given timespan and in a given site owing to a seismic event.

Local Seismic Response (Local Amplification) – Change in amplitude, frequency and duration of seismic motion due to site-specific lithostratigraphic and morphological conditions. This value may be quantified by the ratio of seismic motion at the surface of the site and what would be observed during the same seismic event atop a hypothetical outcrop of rigid rock with a horizontal morphology. Local amplification occurs when this ratio is greater than 1.

Seismic Vulnerability – Propensity of a system to experience damage or loss as a result of a given seismic event. Vulnerability is defined as primary if it refers to the physical damage suffered by a system as a result of the dynamic actions of the event. It is defined as secondary if it refers to the loss that the system suffers as a result of a physical damage. For each system, vulnerability may be expressed directly by defining the distribution of the level of damage or loss caused by a given ground motion or indirectly by defining vulnerability indexes with which damage and ground motion may be correlated. The distribution of the apparent damage to the structural or non-structural elements of a building with changing seismic motion gives a measure of primary vulnerability. The distribution of the cost for repairing an apparent or mechanical damage gives a measure of secondary vulnerability.

ACRONYMS

CRP Conferenza delle Regioni e delle Province autonome
(Conference of Regions and Autonomous Provinces of Italy)

DPC Dipartimento della protezione civile (Civil Protection Department)

GdL Gruppo di lavoro per gli indirizzi e criteri generali per la microzonazione sismica
(SM Working Group – Guidelines for Seismic Microzonation)

NTC Norme tecniche per le costruzioni (Building Code)

SM Seismic Microzonation

1.5 General Notes

Seismic Microzonation (SM) represents a highly useful tool for seismic prevention and risk assessment in land management, for the design of buildings or structures and for emergency planning (Figure 1.5-1). SM has the purpose of identifying local conditions (at a sufficiently large scale, i.e. municipal or sub-municipal) that may significantly alter the characteristics of expected seismic motion or cause major permanent deformations to buildings, structures and infrastructures.

In practice, the SM study is summarised by a map of the investigated area showing:

- zones where seismic motion does not change with respect to expected behaviour under ideal conditions of rigid and flat rock[11]; therefore, the expected motion is considered equivalent to that provided by regional hazard studies;
- zones where seismic motion changes with respect to its expected behaviour under ideal conditions of rigid and flat rock, owing to the lithostratigraphic characteristics of the soil and/or geomorphological features of the investigated area;
- zones where permanent deformations are present or may be triggered by an earthquake (slope instability, liquefaction, surface faulting, differential settlements, etc.).

The data, methodologies and calculations producing the results illustrated by the map are described in an accompanying report.

SM provides a knowledge base of local seismic hazards in different zones and permits the establishment of hazard hierarchies that may be used to plan seismic risk mitigation measures at various scales. An SM study is a tool with different potential capabilities and costs, depending upon the level at which it is prepared. Decisions regarding the implementation and level of study should consider its benefits compared with the costs to be incurred. By improving the understanding of seismic phenomena, SM studies (together with vulnerability and exposure studies) can help optimise seismic risk mitigation resources.

The first section of this document – **Instructions and Criteria** – describes the principles and elements of SM studies and their utilisation in land planning, emergency planning and the design of buildings or structures.

In relation to different contexts and objectives, SM studies may be carried out at various levels of growing complexity and commitment, from Level 1 to Level 3 (Chapter 1.6):

- Level 1 is a preparatory level for actual SM studies; it consists of a collection of existing data that are processed to divide the investigated area into qualitatively homogeneous Microzones in relation to the above-described phenomena;
- Level 2 introduces a quantitative element associated with the homogeneous zones by using additional and focused investigations (where necessary), in addition to defining the SM Map;
- Level 3 produces a *Detailed SM Map* covering particular issues or areas.

11 Type A soil as per the national standard and Eurocode 8.

As part of land-use planning (Chapter 1.7), depending on the various scales and levels of action, SM studies will be carried out for the zones that, as per applicable legislation, may be/are designated to be used for the construction of buildings and/or infrastructures (or whose use may be changed for such purposes) or for civil protection purposes.

SM studies are a fundamental planning tool, as they permit to:

- guide the choice of sites for new settlements;
- define the admissible projects for a given zone;
- schedule investigations and their level;
- formulate policies for projects in urbanised areas;
- define priorities for action.

In emergency planning (Chapter 1.8), at both the municipal and provincial level, SM studies may help identify the strategic elements of an emergency plan and, in general, of civil protection resources.
An understanding of the possible local effects induced by a seismic event in a given area contributes to:

- selecting emergency areas/facilities and strategic buildings in stable zones;
- identifying the "critical" points of road and service infrastructures and the most important buildings or structures in the event of collapse, which may require specific safety assessments.

In the design of new buildings or structures or in projects concerning existing buildings or structures (Chapter 1.9), SM studies highlight possible phenomena of motion amplification induced by the lithostratigraphic and morphological characteristics of the area, as well as instability and permanent deformation triggered by an earthquake.
Hence, SM studies can provide useful data for the design of buildings or structures and their impact will depend on the level at which they are developed and on the characteristics of the buildings or structures in question.
For existing ordinary buildings or structures subject to moderate projects Level 1 data are sufficient.
For new ordinary buildings or structures, the Level 1 results may generally guide the choice of specific investigations to be carried out, while the direct applicability of Level 2 results will depend on whether the characteristics of the homogeneous zones are consistent with those of the site of interest.
Level 3 studies must be used for all strategic buildings or structures to be used for civil protection purposes.

The second section of this document – **Guidelines** – describes selected procedures for preparing SM studies. These procedures, outlined in these *Guidelines for Seismic Microzonation*, represent the operational tools for applying some of the previously mentioned general principles and criteria. In practice, these procedures cover modalities for preparing investigations, constructing the *Investigation Map* at the various levels of SM studies, constructing the *Maps of Seismically Homogeneous Microzones and the SM Map* and developing the schedules for amplification, as well as simplified methods for quantitatively assessing slope instability and liquefaction hazards.

The third section – **Appendixes*** – is a collection of *Technical Datasheets, Reference Schedules* and *Technical Instructions for Geological, Geophysical and Geotechnical Investigations.* This material, together with the **Glossary** and selected **Examples of maps of Seismically Homogeneous Microzones**, provides support and insights for applying the Guidelines.

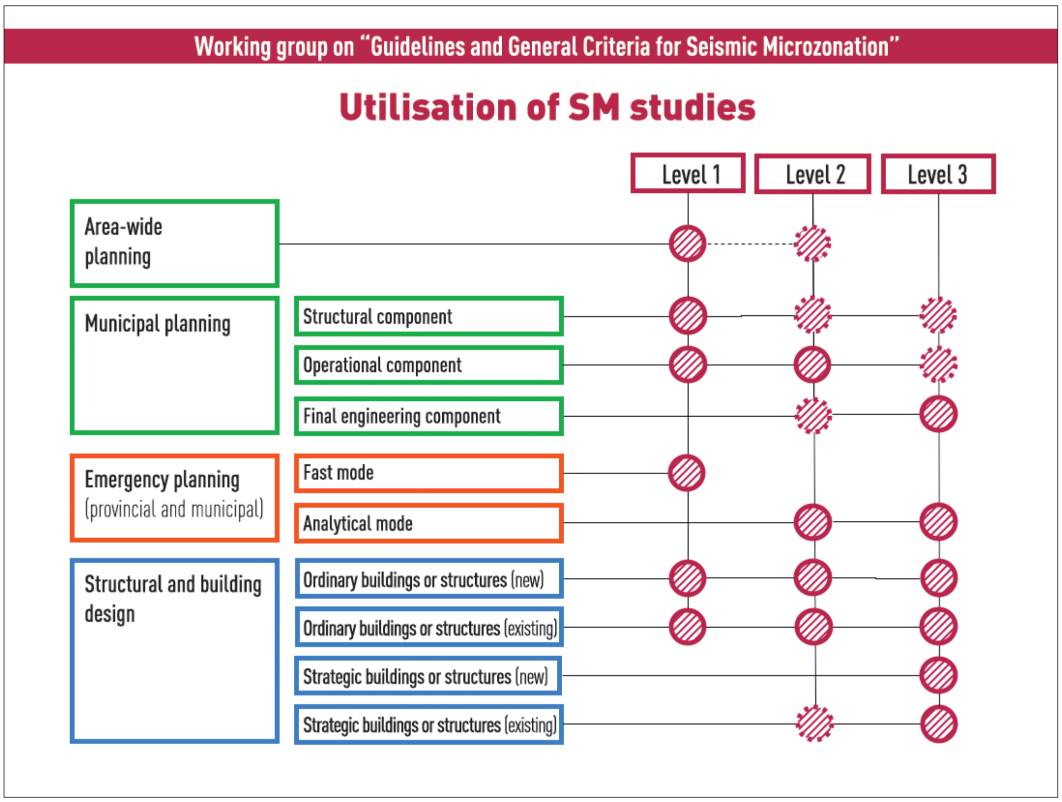

Figura 1.5-1 – SM studies and their use in land-use planning, emergency planning and design of buildings or structures.

* Not included in the english edition.

1.6 Principles and Elements of Seismic Microzonation

1.6.1 GENERAL NOTES

SM studies require the collection and organised storage of prior data and, where necessary, of data from new and specific investigations.
The basic data for SM studies are linked with various disciplines (geology, geomorphology, applied geology, geological engineering, geophysics and structural engineering) and are produced by various sources.
These basic data help build the model of the subsoil, which is a synthetic document and tool propaedeutic to the preparation of the *SM Map*.

The subsoil model is the result of an iterative and interactive process that reconstructs:

- shallow lithological units (recent coverage) and their geometries;
- levels of fracturing;
- relationships with the units of bedrock;
- geotechnical and geophysical features.

Through the repeated analyses and the interaction between information sources, this process must ensure the integration and consistency of different data (Technical Datasheet 3.1.1)*.

The choices to be made for collecting the basic data will depend on the purposes of the studies, on their level and on the availability of economic resources.

The maps summarising the results of the SM studies show:

- zones where no substantial deviations are expected from the ground motion produced by a seismic event on rigid and flat soils;
- zones where ground motion is amplified;
- zones prone to soil and rock slides;
- zones prone to liquefaction;
- zones with active and capable faults;
- zones of differential settlement.

*SM Map*s are typically produced at 1:5,000 – 1:10,000. They are the most appropriate scales for this kind of study, as they are also aligned with national regulations governing medium-scale geographic databases[12]. Maps at 1:5,000 are generally necessary for particularly small study areas.

12 Understanding between State, Regional and Local Entities for the realisation of geographic information systems, Protocol of Understanding dated 26 September 1996 and Integrative Act dates 12 October 2000 (www.intesagis.it).

* Not included in the english edition.

1.6.2 BASIC DATA

1.6.2.1 COLLECTION AND STORAGE OF PRIOR DATA

Generally, when an SM study is initiated, data from prior investigations is available (or in any case to be collected and stored).

Collected data should be adequately checked and stored. It is therefore recommended to:

- develop an appropriate information system to store and manage geographic data (including map data), i.e. a GIS;
- assess the reliability of the data;
- develop a data storage monitoring system;
- develop an appropriate procedure for presenting existing data to assist decision-makers in planning new surveys.

1.6.2.2 SURVEYS AND NEW DATA

The density of data sufficient for a given study depends on the homogeneity of geological, geotechnical and geophysical conditions.

Notes and map elements should be used, to the extent possible, to indicate areas in which uncertainties persist in terms of data acquisition, representation or interpretation. Uncertainties may be geometric (e.g. thickness of a lithostratigraphic unit), phenomenological (e.g. active/quiescent landslide) or numerical (e.g. S wave velocity profile).

The most significant basic data are listed in the following paragraphs, divided by the phenomenon to be investigated, regardless of the selected level of study. For the technical specifications of investigations please refer to the Guidelines and Appendixes.

1.6.2.3 MAP DATA

In addition to basic maps (preferably technical regional maps or municipal aerial photograph surveys), thematic reference maps include: geological maps, lithotechnic unit maps, engineering-geological maps, geomorphological maps and instability maps.

1.6.2.4 REGIONAL HAZARD DATA

Seismic hazard studies are habitually conducted at the national/regional scale by experts appointed by various parties. These studies require proven experience in managing and assessing catalogues of earthquakes, attenuation relationships and statistics. The findings from these studies are then made available for their utilisation, in particular in SM studies to define reference seismic inputs (in spectral form or as accelerograms) and to assess local amplifications or eventual permanent deformations.

With regards to the utilisation of databases, methodologies and results, these studies should comply with the general criteria specified in the national legislation[13].

13 At the time of writing, the reference legislation includes the Ordinances of the President of the Council of Ministers (OPCM) 3274/2003 and 3519/2006 and the Ministerial Decree of 14 January 2008.

1.6.2.5 AMPLIFICATION ASSESSMENT DATA

The assessment of surface amplifications requires the following data:

- regional seismic hazard to define the reference seismic input;
- surface morphology of the site;
- lithostratigraphic section of the site, namely the depth of the seismic bedrock (where identifiable);
- morphology of the seismic bedrock;
- geotechnical classification of soils and geomechanical classification of fractured rock masses;
- S wave velocity profile (V_s);
- fundamental vibration period;
- soil classifications under dynamic conditions.

The recommended investigation methods are as follows:

BASIC DATA	RECOMMENDED INVESTIGATION METHODS
Reference seismic input	Regional hazard analysis and/or instrumental data
Site morphology	Digital terrain model, detailed topographic maps
Lithostratigraphic section	Geological surveys, boreholes
Seismic bedrock depth and buried morphology	Boreholes, geological 2D cross-sections, geophysical investigations
Groundwater	Boreholes, geoelectric soundings
Geotechnical and geomechanical classification	Geomechanical analyses, in-situ tests, lab tests, SPT-CPT correlations
V_s profile	Down-hole, cross-hole, refraction seismology, SASW, MASW, seismic arrays, correlations with geotechnical properties
Fundamental period	Microtremor measurements
Classification of dynamic properties of soils	Resonant column, cyclic torsional shear test, double-specimen simple shear test

1.6.2.6 SLOPE INSTABILITY ASSESSMENT DATA

Slope instability assessments required the following data:

- ground motion (generally in terms of peak ground acceleration, ag);
- topographic profile and slope geometry, i.e. the combination of topography with geomorphological features;
- lithostratigraphic section;
- geotechnical classification;
- landslide model (mobilised material, geometry and depth of the surface rupture, kinematics);
- hydrogeological conditions;
- shear strength characteristics.

The recommended investigation methods are:

BASIC DATA	RECOMMENDED INVESTIGATION METHODS
Ground motion	Local and regional hazard analyses and/or instrumental data
Slope map	Topographic surveys, digital terrain model, detailed topographic maps
Lithostratigraphic section	Geological surveys, boreholes
Geotechnical classification	Standard lab tests, SPT-CPT correlations
Landslide model	Photo interpretation, geological and geomorphological surveys, in-situ geotechnical and geophysical investigations (boreholes, refraction seismic profiles, …)
Groundwater	Boreholes, piezometric investigations
Soil strength vs. stability	Standard lab tests, correlations with in-situ tests (SPT and CPT), cyclic triaxial tests and cyclic simple shear tests

1.6.2.7 LIQUEFACTION PRONENESS ASSESSMENT DATA

Assessments of liquefaction proneness require the following data:

- ground motion (generally in terms of peak ground acceleration, PGA);
- magnitude of expected events;
- lithostratigraphic section;
- granulometry;
- groundwater depth;
- soil strength under cyclic loading.

The recommended investigation methods are as follows:

BASIC DATA	RECOMMENDED INVESTIGATION METHODS
Ground motion	Local and regional hazard analyses and/or instrumental data
Magnitude	Catalogue of earthquakes
Lithostratigraphic section	Boreholes
Grain size and geotechnical classification	Standard lab tests, correlations with in-situ SPT and CPT tests, cyclic triaxial tests, cyclic simple shear tests
Hydrogeology	Piezometric investigations
Soil strength vs. liquefaction	Standard lab tests, correlations with in-situ tests (SPT and CPT), cyclic triaxial tests and cyclic simple shear tests

1.6.2.8 ACTIVE AND CAPABLE FAULT ASSESSMENT DATA

The assessment of active and capable faults requires:

- trace of the fault at the surface;
- general and detailed Lithostratigraphic section;
- extent of dislocations;
- geometry of the fault plane at depth;
- estimated dating of fault movements.

The recommended investigation methods are as follows:

BASIC DATA	RECOMMENDED INVESTIGATION METHODS
Trace at the surface	In-situ surveys, interpretation of aerial photographs
Lithostratigraphic section	Boreholes, geotechnical analyses, paleoseismic analyses
Dislocations and fault ruptures	Paleoseismic analyses
Fault trend at depth	Paleoseismic analyses, geophysical investigations
Estimated dating of movements	Radiometry

1.6.2.9 DIFFERENTIAL SETTLEMENT ASSESSMENT DATA

The assessment of differential settlement requires:

- surface evidence of stratigraphic or tectonic contact of different soils;
- detailed lithostratigraphic section of the two soils;
- geometry of the contact plane at depth.

The recommended investigation methods are as follows:

BASIC DATA	RECOMMENDED INVESTIGATION METHODS
Surface evidence	In-situ surveys, interpretation of aerial photographs
Lithostratigraphic section	Boreholes, geotechnical tests
Contact geometry	Geotechnical and geophysical tests and refraction seismology

1.6.3 LEVELS OF STUDY

SM studies are conducted at 3 Levels.

1.6.3.1 LEVEL 1 – MAP OF SEISMICALLY HOMOGENEOUS MICROZONES

Level 1 has the objective of mapping microzones with homogeneous seismic behaviour at a scale of 1:5,000 – 1:10,000.

Level 1 represents a preparatory and mandatory study for subsequent levels of study. The results of this Level may guide the choice of the next level of study (Level 2 and/or Level 3). Only in particular cases may the results of this level of study be regarded as exhaustive and final[14].

Level 1 requires the prior creation of a general knowledge base concerning a more extensive area than that covered by SM studies.

1.6.3.1.1 Investigation Map

After creating the general knowledge base, the *Investigation Map* for the area under review is to be developed at a scale of 1:10,000 or higher.

14 For instance, in the case of a geological bedrock outcropping in a flat area and identifiable as seismic bedrock. However, also in this case, the geological setting should be carefully analysed as zones apparently identified as outcropping seismic bedrock may often have particularly pervasive surface alterations of considerable thickness and/or fracturing.

The following data should generally be present in an *Investigation Map*:

- location of prior investigations whose data have been collected;
- type of investigations;
- areas where further investigations are considered important or mandatory (in this way, areas with the highest uncertainty of results at this level of study will be reported).

The Guidelines (Chapter 2.2) provide a reference procedure for development of this map.

1.6.3.1.2 Map of Seismically Homogeneous Microzones

The second document to be produced at this level of study is the *Map of Seismically Homogeneous Microzones*. The map displays the microzones where different types of earthquake-induced effects (amplification, slope instability, liquefaction, etc.) are likely to occur. This assessment is based on geological and geomorphological surveys and lithostratigraphic data (these are prior data, already available for the investigated area).

In addition to available basic maps, data that may be used for this map are provided by:

- **a.** previous investigation maps produced at this level;
- **b.** geological and geomorphological maps at a scale of at least 1:10,000, preferably more detailed;
- **c.** lithotechnic unit maps at a scale of 1:10,000;
- **d.** lithostratigraphic logs inferred from borehole data;
- **e.** geolithological cross-sections constructed from data inferred from a., b. and c.;
- **f.** map of hydrogeological hazards (e.g. IFFI - Inventory of Landslide Phenomena in Italy - Project, Provincial Hydrogeological Hazard Maps, plans drawn up by Basin Authorities).

It is worth recalling that when these basic documents are not available, it will not be possible to develop the *Map of Seismically Homogeneous Microzones*.

In the absence of data required to reconstruct the lithostratographic framework, new investigations should be carried out to define Lithostratigraphic section, types and thickness of coverage, the depth of the bedrock and its areas of exposure.

This map identifies the geometries of microzones with potential specific seismic effects.

No seismic input is applied and no numerical quantification of the different effects is carried out.

The microzones indicated on the map are classified according to 3 categories:

- **A)** **stable zones**, where no significant local effects of any nature are assumed (outcropping geological bedrock with flat or slightly inclined morphology – slopes with a gradient of less than 15 degrees);
- **B)** **stable zones prone to local amplification**, where the amplification of seismic motion is expected (as a consequence of local lithostratigraphic and morphological conditions);
- **C)** **zones prone to instability**, where expected and predominant seismic effects may be ascribed to permanent deformations of the investigated area (motion amplification phenomena are not necessarily excluded). The main types of instability are:

- slope instability;
- liquefaction;
- active and capable faults;
- differential settlements.

This document does not address the issues and methodologies for assessing *tsunamis*[15] and *seiches*[16] in instability-prone zones.

Differential settlements[17] are only considered at Level 1 and their location is reported. Generally, these types of instability do not have the same importance as the other phenomena. Differential settlements occur to a limited degree in areas lying close to contacts between formations with very different lithological and mechanical characteristics. This type of phenomena is included in this category for convenience.

The topic of active and capable faults[18] deserves special consideration. The definition of the activity of an active and capable fault should rely on a number of detailed studies conducted by specialists. Only after being technically and scientifically validated should these studies be made available to those dealing with SM. Therefore, at Level 1, the *Map of Seismically Homogeneous Microzones* should only report the faults that have been identified in studies validated by specialists. The homogeneous microzone of an active and capable fault will be mapped in such a way as to include the surface trace of the fault and the soil deformations (secondary ruptures, swelling, settlements, etc.) correlated with the main rupture (Technical Datasheet 3.1.4).*

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15 It is worth briefly recalling that the effects of an underwater earthquake along coastal zones are generally referred to as *tsunami*, a Japanese term for "harbour wave", though the phenomenon has nothing to do with tides (to which the Japanese word refers). A *tsunami* produces a water wave moving at great speed over the surface of the sea and travelling over very long distances before striking the coast and becoming exhausted. This phenomenon may be caused by different events: collapse of volcanic islands, large underwater landslides and major volcanic eruptions. All these phenomena may suddenly pour large volumes of material into the sea. However, similar effects are also induced by abrupt movements of the sea bottom associated with an earthquake. Indeed, when the fault movement responsible for an earthquake suddenly uplifts or lowers a portion of the sea bottom, its oscillation brings about a disturbance in the overlying water mass. This disturbance appears at the surface of the sea as very long waves propagating (in the open sea) at a speed of 500 to 900 km/h. (Obviously, these waves should not be mistaken for the seismic waves generated by the same earthquake, significantly lesser in length and travelling at a much higher speed).
In the ocean, the distance between the crests of two successive *tsunami* waves may reach 300 km, whereas the height of the waves generally does not exceed one metre. As a consequence, in high seas, the passage of a *tsunami* wave may remain unnoticed by people travelling on a ship, although the movement affects the entire water column between the surface and the bottom (note, by comparison, that normal wind-induced ocean waves occur in shallow masses of water and travel at 90 km/h at the most). When they approach the coast and as the water depth decreases, the height of the waves grows, the distance between their crests diminishes and, in the end, they become giant waves rolling toward the coasts and causing massive devastation. If it is the depression between two waves (trough) that first reaches the coast, the sea level suddenly falls and the sea recedes offshore, causing a wide part of the sea bottom to emerge. Immediately afterwards, the wave crest arrives and the sea level rises, forming a wave that may reach heights of up to 30 m, which invades the coast sweeping away all obstacles in its path and carrying them out to the sea with a return wave.

16 Scholars of lacustrine basins use the word *seiche* to define the major and sudden water level variations of the water level of a lake, which appear as free oscillations. *Seiches* are caused by weather disturbances (e.g. strong local winds and fast local changes in barometric pressure), which lower a portion of the lake's surface and uplift another, triggering a swinging oscillation. This oscillation continues, decreasing, even when its cause has ceased. In large lakes, the difference in the water level may exceed 4 metres.
The same word was used to define the disturbances observed in 1755 in numerous European lakes, swamps, canals and harbours after the Lisbon earthquake (form Portugal to the Baltic Sea and from Scotland to the Alps). The cause was deemed to be the passage of surface waves (namely Rayleigh waves), even at a great distance from the epicentre of the earthquake. In areas close to the epicentre of major earthquakes, water level oscillations may be due to other factors, such as the onset of large landslides precipitating to the bottom of a lake and causing the forward and backward oscillation of lake water or an actual *tsunami*. Geological structures may cause oscillations in water bodies. For instance, during the Alaska earthquake of 1964, a high concentration of *seiches* was recorded in the Gulf of Mexico; the *seiches* were likely due to the amplification effects of surface waves in locally thick sediment deposits. During the same event, the Appala

17 "Earthquake-induced vibrations may cause the volumetric compaction of dry granular soil. This improves the dynamic characteristics of the soil (increase in the shear modulus and decrease in the damping coefficient), though it increasingly lowers the surface level of the deposit. Differential settlements occur when this type of soil comes into contact with rock or another very hard soil (thus not subject to compaction). In some instances, these settlements may be of such an extent as to cause serious damage to overlying structures. The importance of this phenomenon may be ascribed to different factors and, in particular, to: relative density, shear deformation amplitude, number of load cycles and stress state". Crespellani, T., *"Elementi per una guida alle indagini di MS" in Indagini geotecniche* (edited by Faccioli, E.), Rome, 1986.

18 An active fault is a fault that has moved at least once for the past 40,000 years (certain lower boundary of radiometric date estimations). An active fault is defined as capable when it reaches the surface, producing a fracture in the soil; the visible line of this rupture at the surface is the surface trace of the fault.

* Not included in the english edition.

The Map should also indicate selected morphological features of the study area and, where identifiable, eventual buried features that may contribute to amplification effects.

Hence, this level of study will make it possible to:

- identify zones with lower local hazards (stable zones);
- plan detailed investigations, based on different types of expected effects;
- identify zones for which further levels of study are required.

The Guidelines (Chapter 2.3) describe a reference procedure for development of the *Map of Seismically Homogeneous Microzones.*
The Map will be accompanied by a descriptive report to optimise its utilisation.
The Appendixes provide examples of these Maps (Chapter 3.5)*.

Table 1.6-1 – Level 1. Summary of investigations, calculations and deliverables

Investigations	Collection of prior data: geological, geomorphological, engineering-geological surveys and boreholes
Computations	Summary of data and available map data
Deliverables	*Investigation Map* *Map of Seismically Homogeneous Microzones* Report describing the Map of Seismically Homogeneous Microzones

1.6.3.2 – LEVEL 2 – *SM MAP*

Level 2 pursues two sequential targets:

- offsetting some of the uncertainties encountered at Level 1 by conducting detailed investigations;
- using simplified methods to provide numerical quantifications (schedules and empirical laws) of local changes to seismic motion at the surface (stable zones prone to local amplification) and permanent deformations (instability-prone zones).

To achieve the above targets, changes may be made to the geometries of the zones previously reported in the *Map of Seismically Homogeneous Microzones*.

1.6.3.2.1 In-depth Investigations

A preliminary step in the preparation of Level 2 studies is the analysis of the *Map of Seismically Homogeneous Microzones* (Level 1), with a view to identifying zones with the highest levels of uncertainty and planning eventual new investigations.
This analysis should consider the morphological, lithostratigraphic and geotechnical features of different zones and supplement them with previously collected and assessed geological, geomorphological, geological-engineering and geotechnical data.
The location of previous and new investigations will be reported in the Investigation Map. This map will also pinpoint zones where further investigations for preparation of Level 3 studies are deemed important, i.e. zones where uncertainties regarding the results of this level of study are more evident.

* Not included in the english edition.

1.6.3.2.2 Numerical Quantifications with Simplified Methods

The result of this level is the *SM Map*. This Map is obtained by associating the numerical quantification of the effects (with simplified methods) with all or part of the zones shown in the *Map of Seismically Homogeneous Microzones*.

The following numerical quantifications may, among others, give rise to the following maps, which represent interim results for this level of study:

- map of stable zones and of stable zones prone to local amplification (amplification factors for two periods of motion and/or response spectra);
- map of zones of permanent deformation (quantitative parameters).

The overlay of these two maps produces the *SM Map*.

The following paragraphs deal with simplified numerical quantification methods for the zones defined in paragraph 1.6.3.1.2 (*Map of Seismically Homogeneous Microzones*).

1.6.3.2.2.1 Stable Zones Prone to Local Amplification

Amplification is quantified by means of "schedules", which define the amplification factors of elastic spectra at the surface, associated with individual lithostratigraphic settings.
The schedules will be prepared by the Regions based on common general criteria and taking into account the seismotectonic and geological features of their territories.

The general criteria for preparing and using the schedules are set out in the Guidelines.

When designing, the use of simplified schedules in lieu of more complex procedures (defined at Level 3) may be taken into consideration only after ensuring that the simplified model adopted for the schedules is consistent with the actual geological, geotechnical and geophysical conditions of the site. The Guidelines provide criteria for validating the results of the schedules under complex geological, geotechnical and geophysical conditions.

The Appendix* contains a selection of reference schedules (Chapter 3.2) that may be used by the Regions:

- as terms of comparison with the schedules prepared by the Regions themselves;
- on an interim basis, pending the preparation of specific regional schedules;
- on a final basis, after the Regions have assessed the applicability of the schedules to their territories.

As an alternative, use may be made only of the methodology for creating the schedules[19]. For the sake of repeatability, this methodology is reported in detail in the Guidelines (Chapter 2.4).

19 The schedules should be prepared for a case history of conditions at least comparable with those specified in the applicable legislation or better rationalised.

* Not included in the english edition.

1.6.3.2.2.2 Instability-Prone Zones

a. Slope instability

The analyses are differentiated between landslides affecting slopes with coherent and incoherent soil and landslides that may occur on slopes with fractured rock masses.

Simplified methods are employed based on schedules and on relations commonly reported in technical-scientific literature. These methods use models and assumptions to estimate the order of magnitude of expected maximum displacements as a result of earthquake-induced slope movements.

For the first group (soil landslides), it should be considered that landslides reactivated by seismic action (second-generation landslides) account for the near-totality of events. In these cases, knowledge of the geometry of the phenomenon and of the parameters of the materials involved generally permits an estimation of maximum expected displacements via simplified dynamic analyses based on Newmark's model (1965; see Chapter 2.6), schedules and empirical relations. These relations, valid for specified slope geometries and rupture mechanisms, use the susceptibility parameter defined by the critical seismic coefficient.

For the second group (fractured rock landslides), estimates are made in order to demarcate the area of the landslide deposit, which is in turn connected with the maximum distances covered by the collapse-prone blocks/dihedral rocks. This areal demarcation derives from empirical relations based on various parameters, e.g. minimum shade angle or equivalent friction angle, as well as predominantly geomorphological observations.

For the first group, estimated displacements are mapped by class of extent of displacement. Conversely, for the second group, potential areas of supply and deposit are mapped and demarcated.

It is recommended to carefully assess the effect of such phenomena as debris avalanches, which may affect infrastructures.

The Guidelines (Chapter 2.6) provide a reference procedure for applying the above-mentioned methods.

b. Liquefaction

Liquefaction is a phenomenon occurring in saturated sandy deposits as a result of a fast and sharp increase in pore pressure. Under these conditions, non-cemented sandy soil acquires shear strength values equal to zero or in any case extremely low, thus becoming a heavy liquid. An increase in pore pressure may be caused by filtration or a strong seismic event.

To cause liquefaction in a liquefaction-prone soil, a strong earthquake is needed. In terms of peak ground acceleration on rock (a_g), complete liquefaction phenomena generally occur during an earthquakes with $a_g > 0.15$.

Liquefaction has surface effects only under particular conditions. In a flat soil, surface effects are negligible if the thickness of the uppermost non-liquefiable layer exceeds the thickness of the underlying liquefiable layer.

A relevant aspect of liquefaction is represented by a change in seismic motion. In general, the occurrence of liquefaction decreases vibration amplitudes and increases the cut-off frequency. Accelerograms of liquefied sites show that, after liquefaction, the amplitudes are reduced and the dominant period lasts some seconds. The combination of these two aspects (moderate acceleration and long periods) may generate major displacements and thus non-negligible damage.

Simplified methods are also used to investigate liquefaction induced by a seismic event. The results of the study should be presented by reporting the liquefaction safety factor vs. depth on each of the investigated vertical soil profiles. For each vertical soil profile, the liquefaction potential index I_L should also be assessed (as defined in paragraph 4.7.1.3).
If
$0 < I_L \leq 5$, the risk of liquefaction is low
$5 < I_L \leq 15$, the risk of liquefaction is high
$I_L > 15$, the risk of liquefaction is extremely high
The results should be reported on a map indicating not only the boundaries of the study area but also the location of the investigated vertical soil profile and the value of the liquefaction index I_L.
If the soil is liquefiable or may experience sharply increasing pore pressures during the reference seismic event, the effects should be assessed in terms of post-seismic permanent deformations. The methodology of calculation is reported in the Guidelines (Chapter 2.7).

c. Active and Capable Faults
No further study is required at this level. This study will instead be carried out at the higher level.

d. Differential Settlement
No further study is required at this level. This study will instead be carried out at the higher level.

The Guidelines (Chapter 2.4) describe a reference procedure for developing the *SM Map*. The Map will be accompanied by a descriptive report to facilitate its use.

Table 1.6-2 Level 2. Summary of investigations, calculations and deliverables

Investigations	In-hole (DH or CH) geophysical investigations, seismic cone, refraction seismology, analyses with active and passive surface wave scatter techniques to estimate V_S, microtremors and seismic events.
Computations	Correlations and comparison with results of Level 1, revision of geological model, schedules for amplification factors, schedules and empirical formulas for slope instability and liquefaction.
Deliverables	*Investigation Map* *SM Map* Report describing the *SM Map*

1.6.3.3 LEVEL 3 – SM MAP WITH DETAILS

The third level of study applies to:

- stable zones prone to local amplification (under complex geological and geotechnical conditions) whose problems cannot be solved using the aforementioned schedules, or when – given the extent of the study area - a global detailed analysis may be useful, or for buildings or structures of particular importance;

- zones prone to particularly severe instabilities owing to the complexity of phenomenon and/or local diffusion, whose problems cannot be solved using the fast track methodologies.

The results of this level may imply changes to the *SM Map*, limited to the zones that have been investigated in more detail.

A programme of tests to be carried out at this Level is to be developed based on the Level 1 and Level 2 studies.
The test programme will be based on the specificity of the case to be studied. The type and number of tests will be adequately described and only tests of proven reliability will be used.
The results of tests conducted to define the geological and geological-engineering model of the subsoil will also be documented.
When planning instruments permit projects in instability-prone areas, documents quantifying the expected potential effects must be prepared. These assessments will be supported by experimental in-situ and laboratory tests carried out in accordance with the principles and methods of applied geology and seismic geological engineering.
The report describing the *Detailed SM Map* must provide a comprehensive description of the processes and computer software used and the results of experimental in-situ and laboratory tests.

Investigations will consist of surveys to collect seismometric data, boreholes, in-hole and surface tests to determine V_s, in-situ and laboratory geotechnical tests (both static and dynamic) and surveys of microtremors.
The calculations will include numerical 1D and 2D analyses to quantify local amplification and dynamic analyses of slope instability and liquefaction susceptibility. The paleoseismic study of active and capable faults is typical at this Level.

The testing programme must be described in the *Investigation Map*, which will indicate

- location of prior investigations;
- location and type of new investigations to define this level of study.

The *SM Map* will be updated with the findings from these investigations.
The investigations will be documented in an attached descriptive report.

Table 1.6-3 – Level 1. Summary of investigations, calculations and deliverables

Investigations	Surveys for acquisition of seismometric data, boreholes, in-hole and surface tests to determine the V_s profile, refraction seismology, in-situ and lab geotechnical tests, microtremors.
Computations	Numerical 1D and 2D analyses for amplification, complete dynamic analyses for estimating permanent deformations.
Deliverables	*Investigation Map* *Detailed SM Map* Report describing the *Detailed SM Map*.

1.6.4 PRESENTATION OF DATA, DATA PROCESSING METHODOLOGIES AND RESULTS

The criteria described in the following paragraphs will be used to present the data, the data processing methodologies and the results, so as to:

- ensure the comparability between all SM studies of different areas;
- facilitate checking and validation by competent parties;
- facilitate the utilisation of SM studies and the identification of bibliographic references by the designer and planner.

The reports describing the studies will have the following layout, with different contents depending on the Level of study:

CHAPTER	CONTENTS
1. Introduction	Aims of the studies, general description of the area, definition of basic map data, aerial photographs, satellite images, list of searched archives/files.
2. Definition of Regional Hazard and Reference Events	Methodology of computation, historical seismicity, Regional hazard maps, ground motion records (if any), active faults. This chapter will be written taking into account basic data, methodologies and results of studies made available by the Regions or by delegated parties or institutions.
3. Geological and Geomorphological Conditions of the Area	Lithostratigraphic characteristics, geological-structural setting, geomorphological setting, geological cross- sections and related maps.
4. Geotechnical and Geophysical Data	Static and dynamic geotechnical parameters, geotechnical and geophysical units. Specification of prior data and newly collected data.
5. Subsoil Model	Integration between collected data.
6. Interpretations and Uncertainties	Identification of data sources, representativeness and uncertainties, weaknesses and strengths, planning for future investigations.
7. Methodologies of Data Processing and Results	Processing of basic data for: amplification; slope instability; liquefaction; estimation of differential settlement; active and capable faults.
8. Map Data *Investigation Map* *Map of Seismically Homogeneous Microzones* *SM Map*	Procedure for developing maps, level of reliability of results and uncertainties. For Regions that require comparisons with national legislation, discussion of results for this topic.
9. Comparison with Damage During Past Events	Comparisons with the distribution of damage from past events (where available), notes on the vulnerability of the structures involved.
10. References	
11. Annexes	

1.6.5 VALIDATION OF SM STUDIES

Prior to their adoption, SM studies must be validated by a party with adequate multidisciplinary competences to verify their compliance with the Guidelines adopted by Regional/Provincial Governments. The validating party will be designated by the Region from among those parties responsible for planning activities and monitoring compliance with the technical standards.

If the validating party is unable to accomplish this task, an external party will be designated.

To guarantee uniform results and homogeneous SM data for municipalities straddling regional borders, the Regions concerned will determine the venues for the comparison of data and related procedures.

1.6.6 UPDATING OF DATA AND RESULTS

SM studies must be updated, taking into account - among others - improvements in technologies of investigation, in the wake of:

- a seismic event, based on analyses of the distribution of damage (Technical Datasheet 3.1.9)*;
- important surveys for data acquisition (e.g. construction of strategic buildings or structures);
- major new strategic or siting choices in land-use, urban planning or emergency planning.

As SM studies require the acquisition of available data, regional and other local governments should keep their databases constantly up-to-date; as the SM studies imply the critical analysis of prior data and new investigations, they should offer the opportunity to update the databases.

* Not- included in the english edition.

1.7 Territorial and Urban Planning

1.7.1 GENERAL

Within the framework of territorial and urban planning, SM studies integrate the knowledge of those components that give rise to seismic risk and provide decision-making criteria related to the prevention and mitigation of this same risk, according to a gradual and programmatic approach implemented at various scales and levels of planning.

At the urban scale, the identification of local seismic hazards and the levels of vulnerability of the exposed elements and systems is essential to the assessment of the risk zones and, thus, to the introduction of safety elements as key factors for development and siting decisions.

SM studies are applied at different geographic levels, corresponding to different levels of planning (for the purposes of these Guidelines):

- area-wide planning (Provincial Plans and other Territorial Plans);
- municipal planning (in its different components: structural, operational and final, as described in the following paragraphs).

1.7.2 AREA-WIDE PLANNING (PROVINCIAL PLANS AND OTHER TERRITORIAL PLANS)

1.7.2.1 OBJECTIVES

In the specific field of seismic risk, the area-wide planning process:

- incorporates the targets of seismic risk mitigation, where they have been set at the regional and national level;
- for the geographic area involved, adopts and describes the methodologies and procedures defined by regional legislation;
- identifies priority areas for action and investigation, as well as the required levels of study, also in view of resource planning;
- contributes to creating a knowledge base for the investigated area.

1.7.2.2 LEVEL OF MICROZONATION STUDIES

Despite significant limitations resulting from the absence of quantitative information, at the area-wide level of territorial planning, the preparation of Level 1 studies, when realised in an extensive manner, is strategic to national risk mitigation policies.

The provincial territorial level is generally optimal to guarantee - through Level 1 studies - a homogeneous knowledge base. This knowledge base may be correlated with the levels of area-wide planning typical to the provincial territory.

Level 1 studies represent the fundamental knowledge base for all Municipalities classified as high-seismicity zones (zone 1), average-seismicity zones (zone 2), low-seismicity zones (zone 3) and possibly very low-seismicity zones (zone 4), regardless of the knowledge base of the higher geographic levels. For Municipalities classified under zone 4, Level 1 studies provide the required basic knowledge, where the Region requires these Municipalities to apply anti-seismic legislation or adopt seismic risk mitigation targets[20] (see Seismic Zoning Technical Datasheet and Seismic Classification of Municipalities)*. These studies will be carried out taking into account the need for narrowing the investigation and for setting priorities under the criteria explained in the following paragraphs.

As a general rule, these studies should not be extended to the entire territorial area, as their costs and timescales may not be justified by collective benefits. For this purpose, the categories of areas to be excluded from these studies are identified as "excluded areas".

The excluded areas may be defined as those areas that may not accommodate settlements or infrastructures owing to their context or to relevant legislation. On a first-cut assumption and by way of example, these areas may be identified with those where construction of settlements is excluded under protection measures or rules that significantly limit their use. Depending on their contexts and legislation, the Regions will identify the categories of areas where Level 1 studies, where they represent a burden for the community, are to be excluded. The Provinces, in cooperation with the Municipalities, will designate the areas corresponding to the categories indicated by the Regions.

1.7.2.3 METHODS FOR UTILISING THESE STUDIES

Level 1 studies not only support the supra-municipal decision-making process, but also contribute to creating a knowledge base for municipal planning.

The development of the *Map of Seismically Homogeneous Microzones* (Level 1) will thus be used in area-wide planning to:

- schedule investigations and define their utilisation;
- guide and validate planning and siting choices of supra-municipal interest;
- guide the siting of primary operational, logistic and infrastructural elements, in line with emergency plans;
- provide the parties responsible for municipal planning with a map of the municipal territory to be used in the development of its plans;
- integrate hazard studies with other studies typical of seismic risk analysis.

When the area-wide planning process involves multi-criteria assessments, strategic assessments of plans or similar procedures (Strategic Environmental Assessments - SEAs - or other), it will also organically include local seismic hazard assessments that take into account Level 1 studies. If specific seismic risk assessments are planned, the seismic hazard indicators, if any, will be integrated, consistent and homogeneous with those concerning exposure and vulnerability. The *Map of Seismically Homogeneous Microzones* may be summarized, for the purposes of the planning process, in the following way:

20 Reference is made to the seismic classification of Municipalities as per OPCM 3274/2003 in view of the application of technical standards. The seismic risk mitigation targets, priorities and action plans should be consistent with the criteria of classification of the Municipalities.

* Not included in the english edition.

ZONES	LOCAL PLANNING OF LAND USES/CHANGES, RELATED PROCEDURES AND NEED FOR IN-DEPTH INVESTIGATIONS
AREAS EXCLUDED FROM SM STUDIES	Areas where the application of SM studies is to be avoided.
SEISMICALLY HOMOGENEOUS MICROZONES	
1. Stable zones	No need for in-depth investigations.
2. Amplification-prone stable zones	Possible need for in-depth investigations (Level 2 and Level 3), taking into account - among others – siting choices. Identification of parties in charge of conducting in-depth investigations.
3. Instability-prone zones	Possible need for in-depth investigations (Level 2 and Level 3), taking into account - among others – siting choices. Identification of parties in charge of conducting in-depth investigations. If these zones already accommodate settlements, they should have priority in terms of in-depth investigations (Level 2 and Level 3, associated with risk assessments at appropriate level) and actions.
3.a Slope instabilities 3.b Active and capable faults	Possibly excluded from plans for new settlements, unless detailed analyses are carried out. These analyses (including sector-specific, land planning and seismic risk studies) should be extended to the entire territory and demonstrate the non-feasibility of alternative siting choices. Possible exclusion from plans for new infrastructures, unless: i) specific investigations and assessments are carried out; and ii) the individual projects involve the design of systems ensuring the safety and durability of the buildings or structures.
3.c Liquefaction 3.d Differential settlements	Same rules as for instability-prone zones.

1.7.3 MUNICIPAL PLANNING

1.7.3.1 GENERAL

With regard to seismic risk, the municipal planning process:

- adopts SM studies to build a knowledge base of the municipal territory;
- sets seismic risk mitigation targets, in line with the targets and Guidelines possibly formulated at regional and provincial level;
- sets priorities for action and study, defining the related level and taking into account planning choices and resource planning.

Apart from the specificities of the different regional regulatory-legislative frameworks, the contents of a municipal plan may be divided into the following components, for the purposes of these Guidelines:

- structural component;
- operational component;
- final implementation component.

Table 1.7-1 shows a possible correlation between the contents of a municipal plan and the urban planning instruments adopted by individual Regions.

1.7.3.2 THE STRUCTURAL COMPONENT

The structural component of a municipal plan defines:

- existing and planned invariants in terms of history, culture, environment, infrastructures and settlements;
- general strategies and objectives of transformation;

- specific goals and policies of action;
- procedures and areas of transformation;
- priorities and stages of the planning process which should incorporate in-depth investigations.

The structural component of a municipal plan adopts and integrates priorities in terms of seismic risk mitigation, limitations concerning instability-prone zones and indications on in-depth investigations, contained in area-wide planning documents or instruments (provincial or other territorial plans), where available.

The structural component provides indications on the responsible parties and the procedures for implementing SM studies at various levels.

The Municipalities will adopt the *Map of Seismically Homogeneous Microzones* (Level 1), prepared by higher-level territorial governments or, in the absence of such map, they will develop one on their own initiative.

The *Map of Seismically Homogeneous Microzones* represents the specific content of the structural component of the plan and a fundamental element for assessing and making choices.

If specific tests and analyses (studies of Level 2 or Level 3) show substantial deviations from the *Map of Seismically Homogeneous Microzones*, these deviations will be taken into account in the planning of urban transformations and help update the knowledge base of the investigated area. Based on the deviations from the *Map of Seismically Homogeneous Microzones*, the Regions will determine the need for revising the planned methods of urban transformation, including the possible use of variations to structural plans.

An integral part of the structural component is the identification of relations between categories of intervention, the application of anti-seismic legislation and the utilisation of SM studies, possibly on the basis of guidelines issued by Regional or Provincial Governments.

SM studies will take into account the specificities of the regional legislation, of the planning and social-cultural context, of the stage of definition of the structural component of the plan (first draft or general or partial variation). In this way, SM studies may generally help define the following contents (individually or integrated between them):

- general and/or sector-specific urban planning strategies, possibly including specific choices in terms of siting and explicit targets in terms of seismic risk mitigation;
- specific seismic risk mitigation policies, actions and projects, which may translate into siting choices;
- specific siting choices.

1.7.3.2.1 Urban planning strategies

To prepare the plan and formulate strategies, the need arises for conducting in-depth analyses and assessments, aimed at defining priorities, programs, siting choices and projects. Analyses and assessments will include those concerning the seismic risk, based on seismic hazard analyses and SM studies. These assessments may fall under the Strategic Environmental Assessment (SEA) or other assessment methods (multi-criteria, costs-benefits, etc.) referred to by regional legislation and adopted by local government. The appropriate level of SM to be used for formulating strategies is generally represented by the *Map of Seismically Homogeneous Microzones*. However, if more detailed levels of study are selected for overall risk assessment (e.g. vulnerability and exposure studies), the appropriate level of SM will be chosen consistently with the level of detail adopted for the other studies.

In brief, the *Map of Seismically Homogeneous Microzones* has the purpose of guiding planning and siting choices:

- by guiding the choice of new areas;
- by defining the projects admissible in a given area and the related procedures;
- by guiding the siting of primary operational, logistic and infrastructural elements, in line with emergency plans, if any;
- by indicating programs, if any, for in-depth investigations.

The *Map of Seismically Homogeneous Microzones* is applied when determining the procedures for the operational component and for the final implementation component (paragraphs 1.7.3.3 and 1.7.3.4).

In this connection, notwithstanding the following paragraphs concerning the operational and final implementation components, the structural component of the plan provides indications for defining the categories of areas for which detailed SM studies (Level 2 or Level 3) are required, also on the basis of the planned categories of direct action. These cases may be identified, among others, based on the criteria or guidelines possibly formulated by the Regions or Provinces.

1.7.3.2.2 Specific seismic risk mitigation policies

This paragraph deals with assessments that are geared to identify specific seismic prevention policies and actions, such as:

- setting priorities for risk mitigation actions in built-up areas;
- identifying urban systems to assess the urban response to an earthquake, the overcoming of the emergency and the start-up of the recovery phase after the seismic event (studies to identify the MUS - Minimum Urban Structure),
- identifying areas of high exposure and vulnerability so as to minimise risk.

Also in this case, the *Map of Seismically Homogeneous Microzones* may be regarded as the required minimum level of knowledge. Nevertheless, if more detailed vulnerability and exposure studies are deemed necessary, the required level of SM studies may be differentiated and should be consistent therewith.

The *Map of Seismically Homogeneous Microzones* may also be narrowed exclusively to those areas where policies of action are to be implemented.

1.7.3.2.3 Siting choices

If the prevailing approach to the plan is based on siting choices (e.g. new expansion projects or infrastructures), the level of SM studies should be selected in line with the assessments to be made. If the choices are made on the basis of quantitative analyses, the required level should be at least equal to that of the *SM Map* (Level 2).

1.7.3.3 OPERATIONAL COMPONENT

In seismic risk mitigation, the operational component incorporates the structural component, namely:
- the strategies and assessments based on risk analyses;
- the plan policies that are focused on seismic prevention;
- the siting choices for new settlements and infrastructures.

1.7.3.3.1 Incorporation of urban planning strategies

Based on the seismic risk analyses defined in the structural component, the operational component incorporates choices concerning:
- new areas;
- projects admissible in individual areas and their procedures;
- procedures of action in already urbanised areas;
- prescriptions especially for zones whose use is limited by conditions of instability, as shown in the *Map of Seismically Homogeneous Microzones.*

Based on the selected strategies, the operational component will identify:
- rules and prescriptions for mitigating the risk in individual areas and new areas;
- areas and buildings at high risk requiring specific investigations and specific maintenance or actions;
- priorities for actions concerning strategic and important buildings.

For this purpose, programs of in-depth investigations are formulated for the individual zones specified in the structural component, based on the indications contained in the same component. Furthermore, the responsible parties and the procedures for conducting the in-depth investigations during the implementation stage are identified. In laying down rules and prescriptions for new areas, it should be taken into account that:
- in areas to be urbanised that are included in the amplification-prone zones reported in the *Map of Seismically Homogeneous Microzones*, the definition of quality and performance parameters requires knowledge elements that are typical of the *SM Map* (Level 2); in instability-prone zones, the investigations specified in the structural component are necessary;
- in areas to be used for farming or other areas excluded from the analysis of the *Map of Seismically Homogeneous Microzones*, the rules established for the design of buildings or structures (Chapter 1.9) will apply to projects concerning existing or new buildings.

With regard to the identification of high-risk areas and buildings, various conditions may arise:

- the high risk is due to the elevated local seismic hazard, for instance because the areas involved fall within the instability-prone zones already recorded in the *Map of Seismically Homogeneous Microzones*: in this case, the operational component will involve additional investigations and procedures of action;
- the high risk is mainly due to high exposure or high vulnerability of the exposed elements: in this case, the operational component will verify the conditions for decreasing exposure levels and define procedures, programs and responsible parties for conducting additional investigations aimed at carefully assessing vulnerability and, consequently, at planning mitigation actions.

To set priorities for actions concerning strategic and important buildings, reliance will be made on homogeneous data: at least the levels of knowledge of the *SM Map* (Level 2) and the summary datasheets of seismic verifications[21].

Successive plans for actions of correction and improvement must consider the indications regarding the application of anti-seismic legislation as described in chapter 1.9.

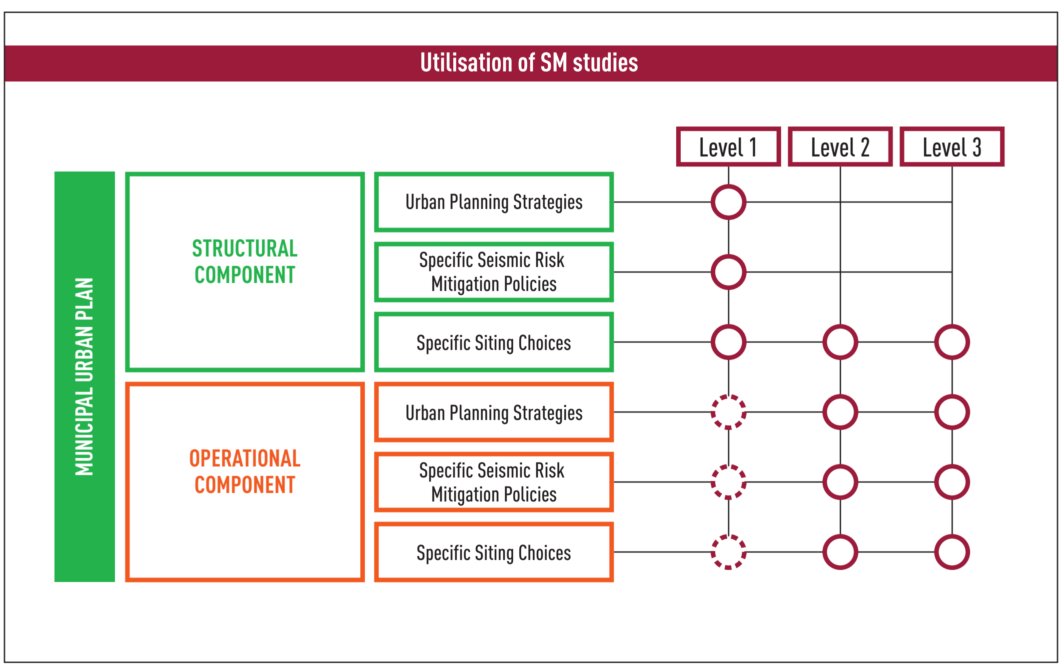

Figure 1.7-1 – Utilisation of SM studies in the municipal planning process

21 Article 2 of OPCM 3274/03 provides that these buildings or structures shall be subject to seismic verification within 5 years from the publication of the same OPCM (May 2003). This deadline was extended to 2010 by Law no. 31 of 28 February 2008. For State-owned buildings or structures, the verifications shall be summarised in appropriate forms (contained in OPCM 3502/06). Various Regions have adopted similar forms also for the buildings and structures falling under their responsibility.

1.7.3.3.2 Integration of specific seismic risk mitigation policies

In seismic prevention policies, the operational component may become a specific instrument to mitigate the seismic risk, as part of the more general purpose of controlling urban and territorial quality defined through the structural component. In this sense, the operational component may introduce specific goals of seismic prevention (priorities for risk mitigation actions in built-up areas; identification of urban systems for assessing the urban response to an earthquake, overcoming the emergency and the start-up of the recovery phase after the seismic event; identification of areas of high exposure and vulnerability with a view to minimising risk), thus contributing to the targets set in the structural component, by highlighting and describing the procedures for their achievement.

1.7.3.3.3 Integration of siting choices

By incorporating the siting indications of the structural component, the operational component: i) defines the sites in detail (if they fall within the amplification-prone zones or the instability-prone zones reported in the *Map of Seismically Homogeneous Microzones*) by using the *SM Map* (Level 2) or the investigations of Level 3; and ii) specifies their geographic boundaries and behaviours in case of hazard. The operational component defines the types, procedures and density of the tests and investigations to be carried out in the sites designated for new settlements and infrastructures, where they have not been defined in the structural component. These investigations may confirm the Microzones and associate them with specific quantitative parameters or modify them locally.

1.7.3.4 FINAL IMPLEMENTATION COMPONENT

The final implementation component will define (where not defined by the operational component):

- the levels of investigation of the SM studies;
- the parties implementing the SM studies.

The final implementation component will lay down the prescriptions and rules defined by the operational component in terms of risk mitigation in the identified areas, both by applying anti-seismic legislation to reduce vulnerability and by taking specific actions to possibly reduce exposure. The final component will involve the implementation of the programs of investigations defined by the operational component.

Table 1.7-1 – Correlation between the contents of a municipal plan and the urban planning instruments adopted by individual Regions.

Regions	Law	Structural Component	Operational Component	Final Component
Abruzzo	LR 18/1983	PRG		PRE - PA
Basilicata	LR 23/1999	PSC	PO/RU	PA
Calabria	LR 19/2002	PSC	POT	PAU
Campania	LR 16/2004	PUC		PUA
Emilia-Romagna	LR 20/2000	PSC	POC	PUA
Friuli Venezia Giiulia	LR 52/1991	PRGC		PRPC
Lazio	LR 38/1999	PUCG		PUOC
Liguria	LR 36/1997	PUC	PUO	PrA
Lombardia	LR 12/2005	PGT (DdP)	PGT(PdR)	PA
Marche	LR 34/1992	PRG		PA
Molise	(LR 24/1989)	PRG		PA
Piemonte	LR 56/1977	PRG		PA
Puglia	LR 20/2001	PUG		PUE
Sardegna	LR 45/1989	PUC		PA
Sicilia	LR 71/1978	PRG		PA
Toscana	LR 1/2005	PSC	RU	PCI - PA
Trentino Alto Adige Provincia di Bolzano	LP 13/1997	PUC		PA
Trentino Alto Adige Provincia di Trento	LP 22/1991	PRG		PA
Umbria	LR 11/2005	PRG (Parte strutturale)	PRG (Parte operativa)	PA
Valle d'Aosta	LR 11/1998	PRG		PUD
Veneto	LR 11/2004	PAT	PI	PUA

DdP Plan Document
PCI Complex Action Plan
PO Operational Plan
PRE Final Master Plan
PSC Municipal Structural Plan
PUD Detailed Urban Plan
PUOC Municipal Operational Urban Plan
PA Implementation Plans (various)
PdR Plan of Rules
POT Operational Schedule
PRG General Master Plan
PUA Implementing Urban Plan
PUE Final Urban Plan
RU Urban Planning Rules
PAT Land Management Plan
PGT Land Use Plan
PP Detailed Plan
PRGC Municipal General Master Plan
PUC Municipal Urban Plan
PUG General Urban Plan
PAU Unitary Implementation Plan
PI Plan of Actions
PrA Implementation Program
PRPC Municipal Detailed Master Plan
PUCG General Municipal Urban Plan
PUO Operational Urban Project

The final implementation component embodies all the procedures having the purpose to regulate direct actions. With a view to fitting these procedures of action within seismic risk mitigation strategies, the local government will take the initiative of drawing up the *SM Map* and making it available. The *SM Map*, prepared for the areas of direct action, will be extended to all the amplification-prone zones and to all the instability-prone zones where categories of actions involving SM studies, also in view of anti-seismic legislation, are planned.
The identification of relations between categories of action, application of anti-seismic rules and utilisation of SM studies are an integral part of the structural component (paragraph 1.7.3.2).

By issuing technical implementation and urban planning rules, the local government ensures that the map will become a reference tool that must be considered in projects for the construction of new buildings or structures or the retrofitting/improvement of existing buildings or structures. This tool will make it possible to verify whether these projects are consistent with the map data. The map will also highlight the zones where more detailed investigations (Level 3) are needed.

1.8 Emergency planning*

1.8.1 GENERAL

The "Augustus" method carried out by the Civil Protection Department in 1997 defines emergency planning as "*the set of operational procedures of action to be activated upon the occurrence of the expected event indicated in an appropriate scenario*".

In particular, emergency planning includes the set of activities aimed at developing and maintaining shared procedures for preventing, controlling, managing and mitigating an emergency condition. Emergency planning:

- is defined as a process of prediction of risks and preparation for emergencies; the process is supported by procedures ensuring the preparedness of the parties involved in emergency management and the updating of the same planning;
- includes drills and population awareness actions, as well as periodical updates to accommodate changes in the physical features of a given area or in its uses;
- is also connected with territorial and urban planning, as it provides indications on primary operational, logistic and infrastructural elements.
- indicates the availability of structural resources for emergency management.

The emergency plan consists of three parts: general part, plan outline and a model of action.
The general part reports the basic data (maps, including technical maps) and the damage scenarios.
The plan outline lists the objectives of the plan.
Finally, the model of action identifies the set of the orderly and procedure-coordinated actions to be deployed by the operational civil protection resources (human and material) upon the occurrence of the event.

Emergency planning is divided into a provincial plan and a municipal plan.

The provincial plan gathers all the data about the provincial territory from the Municipalities and the Region, so as to draw up possible damage scenarios involving the entire Province. The plan identifies

* In 2012 the Civil Protection Department introduced the analysis of the Emergency Limit Condition (ELC).
This analysis constitutes a first tool focused on the integration of territorial interventions of seismic risk mitigation at the municipal scale, and deals with activities for the verification of systems of emergency situation management.
Of the diverse limit conditions definable for urban settlements, the ELC corresponds with the condition by which, in the wake of a seismic event, the entirety of an urban settlement suffers physical and functional damages sufficient to produce an interruption in almost all urban functions, including residential systems. The urban settlement conserves the use of the majority of its strategic functions during an emergency together with its connections and accessibility from the surrounding territory.
The analysis of the ELC must always be conducted in concomitance with SM studies and, as with the latter, it is necessary to respect specific standards of surveying and archiving (Analysis of the Emergency Limit Condition. ELC. Graphic and Data Archiving Standards).
The ELC analysis for a specific settlement requires the compulsory identification of the following items:
- emergency situation management structures;
- the system of interconnections between these structures and the network of territorial access.

ELC analysis represents a new operative tool focused on increasing the safety of inhabited areas. This tool is compared with other experiences matured to date across the country.
Internet resources:
http://www.protezionecivile.gov.it/jcms/it/commissione_opcm_3907.wp
http://www.protezionecivile.gov.it/jcms/it/cle.wp

objectives for coordinated civil protection response, as well as procedures for activating the operational civil protection resources present in the provincial territory. Finally, the plan identifies the procedures for the orderly and coordinated deployment of the provincial operational civil protection resources, supported by regional and national external forces.

The municipal plan collects all the data of the municipal territory, so as to draw up the related possible damage scenarios. Therefore, it specifies all the emergency response, rescue & relief actions to be taken by the various local civil protection teams. Under the applicable legislation on civil protection (Law no. 225 of 1992 and Legislative Decree no. 112 of 1998, as subsequently amended), the preparation of provincial emergency plans falls under the responsibility of provincial governments on the basis of regional Guidelines, whereas municipal governments (individually or associated) have the task of preparing municipal emergency plans.

The Appendixes* show 3 Technical Datasheets with details about the topics covered in this Chapter: the first on emergency planning (Technical Datasheet 3.1.11), the second on damage scenarios (Technical Datasheet 3.1.12) and the third on modelling of amplification effects in damage scenarios (Technical Datasheet 3.1.13).

1.8.2 OBJECTIVES

The starting point for drawing up both provincial and municipal earthquake emergency plans is the damage scenario assumed for the reference seismic event.
The scenario makes it possible to quantify both human and material civil protection resources to be allocated for the overall management of the emergency.
Knowledge of local effects plays a key role in damage scenario analysis, as these effects may significantly change the in-situ parameters of the earthquake, induce permanent deformations and considerably affect also the estimation of civil protection resources.

For both plans, the *Map of Seismically Homogeneous Microzones* (Level 1) is the basic level of knowledge, which helps identify and make an informed choice of the strategic elements of an emergency plan, such as emergency areas, strategic and important buildings, infrastructural systems. The *Map of Seismic Microzonation* (Level 2) is the level of knowledge that may be used to assess the safety of specific buildings or structures, e.g. those considered strategic for civil protection coordination (town hall, fire brigade station, etc.) and those which may become important in the event of collapse (schools, particularly crowded buildings, activities at risk of major incidents, etc.). The same map may also yield useful data for preparing more detailed damage scenarios. The *Detailed Map of Seismic Microzonation* (Level 3) is a level of knowledge that may be used for the seismic verification of existing strategic and significant buildings or structures.

All the documentation pertaining to SM studies and databases for the investigated sectors (population, road network, primary and secondary infrastructures, hydrogeology, etc.) is usually collected and organised into a geographic information system (GIS).

* Not included in the english edition.

1.8.3 UTILISATION OF SM STUDIES

Generally, in emergency planning, the data obtained from SM studies may be used in two modes: fast and analytical. The fast mode uses qualitative data from Level 1 SM studies. The analytical mode uses quantitative data from Level 2 and 3 SM studies. The procedures described in the following paragraphs apply both to the drawing-up of a new emergency plan and to the revision of an existing emergency plan, for both levels of municipal and provincial planning. Table 1.8-1 summarises how the findings from SM studies may be used in emergency planning.

1.8.3.1 FAST MODE (USE OF LEVEL 1)

The fast mode is applied by overlaying the map of strategic civil protection resources (location of strategic and important buildings and of emergency areas and facilities), the map of the road network and the *Map of Seismically Homogeneous Microzones* (demarcation of instability-prone zones, of local amplification-prone stable zones and of stable zones), so as to identify both adequate and critical situations.

The *Map of Seismically Homogeneous Microzones* (Level 1) is used to:

- identify and assess the adequacy of emergency areas;
- initially verify critical points, if any, in the road infrastructure and service systems, in support of seismic emergency management;
- identify strategic and emergency buildings or structures (strategic buildings for civil protection and accommodation facilities) on which specific investigations and seismic safety assessment may possibly be carried out.

1.8.3.1.1 Emergency areas

One of the primary objectives for an appropriate emergency planning process is the identification of the areas that are required to manage a crisis. Recent experiences confirmed the need for identifying and possibly preparing – during a time of "non-crisis" - areas that are suitable for organising population rescue & relief operations. These areas may be defined as follows:

- waiting areas (or meeting points): areas where the population first gathers after the occurrence of an event and which may be reached through a safe route;
- accommodation (or shelter) areas: areas giving adequate and temporary shelter to the population (camps with tents and/or trailers, containers and/or small wooden houses), where the identity and health status of individual persons are initially checked and emergency care is provided;
- rescue & relief areas (or gathering areas for rescue & relief teams and facilities): areas where base camps are set up to accommodate operational teams, volunteers and facilities providing rescue & relief services to the population.

Generally, the identification and choice of these areas is based on criteria of safety, accessibility and the availability of services. All of the areas that may fall totally or partially within instability-prone zones reported in the *Map of Seismically Homogeneous Microzones* will be excluded from the candidate emergency areas. Focused investigations may be required for accommodation areas where camps of containers and/or small wooden houses will be set up, and which will be used for a longer period.

It should be pointed out that the results of SM studies are only one of the elements to be used for identifying and selecting the above areas, as there may be other hazards in the area (e.g. floods, landslides of a hydrogeological nature, etc.) or critical points in its service infrastructures (road network, water and power utilities, etc.); these hazards and criticalities should be taken into due consideration in the final choice.

1.8.3.1.2 Road infrastructures

During the planning process, account should be taken of such aspects as the urban configuration of built-up areas or the presence of bridges or other infrastructures exposed to damage or interruptions upon a seismic event. These aspects will help identify the potential sources of hazard and the possible routes of exit or connection with strategic buildings.
In particular, the analyses of the urban setting, of the road network and of communication flows represent the basis for planning and managing exit and connection routes.
Based on the above analyses, a map of the road network will be drawn up. The map will show:

- critical points (bridges, road narrowings, etc.);
- exit routes;
- rescue & relief routes;
- banned traffic areas.

By overlaying this map on the *Map of Seismically Homogeneous Microzones* (Level 1), all the roads located in instability-prone zones and local amplification-prone stable zones will be detected. Then, the redundancy of the roads located in instability-prone zones vs. the overall road network will be assessed.

If redundancy is low, i.e. the road network is one of the few connection routes, it will be marked in the emergency plan as "critical" and its vulnerability will be evaluated with simplified methods. The same will be done for the buildings located in the immediate vicinity of the critical points, for which reference may be made to the vulnerability assessment forms available in the literature[22]. If redundancy is high, i.e. if an alternative and reliable road system is available, no additional specific studies will be needed; the emergency plan will merely list the actions to be taken in order to ban traffic on the possibly interrupted road network and put in place alternative road signs.

1.8.3.1.3 Service infrastructures

To make an initial assessment of the adequacy of the service infrastructures (aqueducts, gas pipelines, power grids, water supply and sewage systems), the points of such infrastructures which totally or partially fall within instability-prone zones will be marked in the emergency plan as "critical". The seismic safety of these points may be more thoroughly studied by using, among others, levels 2 or 3 SM studies, where available.

22 For instance, the level I and II datasheets for masonry buildings and the level I datasheets for reinforced-concrete buildings, issued by GNDT, National Team for Earthquake Defence (CNR-GNDT, 1993).

1.8.3.1.4 Strategic buildings and emergency facilities

Strategic buildings for civil protection relief & rescue services and emergency facilities (buildings accommodating the evacuated population) will not be used under emergency conditions if they totally or partially fall within instability-prone zones. This exclusion will be notified to their owners, also in view of the prescribed safety verifications[23]. These verifications may rely on the results of SM studies, as described in paragraph 1.9.3.4.

1.8.3.1.5 Other buildings or structures

The emergency plan will highlight the other important buildings or structures which may totally or partially fall within instability-prone zones: i) buildings or structures which may collapse after the earthquake (schools, possibly crowded public offices, churches, etc.); ii) buildings or structures which may cause serious environmental damage (industries at risk of major incidents, etc.); and iii) cultural assets of particular interest. In defining the model of action, all these aspects will be taken into account. The owners of these buildings or structures will be notified thereof, also in view of the prescribed safety verifications[24]. These verifications may rely on the results of SM studies.

1.8.3.2 ANALYTICAL MODE (USE OF LEVEL 2)

The analytical mode uses the quantitative data obtained form SM studies to conduct specific risk assessments on buildings or structures that are strategic for civil protection purposes or which may be important in case of collapse after the earthquake, as pointed out in paragraph 1.9.3.4. Moreover, detailed seismic assessments will be carried out on these buildings or structures, with priority for seismic zones 1 and 2, regardless of the local seismic hazard.

1.8.3.2.1 Emergency areas

For emergency areas, the availability of quantitative data on amplification- and instability-prone zones will not change the assessment that may have been carried out using the fast mode, according to the considerations made in paragraph 1.8.3.1. An exception is represented by the accommodation areas to be used for setting up camps of containers and/or small wooden houses, given their predictable longer period of utilisation. These areas may require investigations to quantify and characterise possible increases in local seismic action.

1.8.3.2.2 2 Road infrastructures

For road infrastructures, the availability of quantitative data on amplification-prone stable zones and on instability-prone zones may change the criticality assessment previously carried out in fast mode.

In particular, similarly to what has been described in paragraph 1.8.3.1, the redundancy of roads located in critical points and crossing instability-prone or amplification-prone zones vs. the overall road network will be assessed.

23 OPCM - Ordinanza del Presidente del Consiglio dei Ministri 20 March 2003, n. 3274, article 2.

24 Ibid.

If redundancy is high, the emergency plan will report the actions to be taken to ban traffic on the possibly interrupted roads, identify alternative roads and put in place alternative road signs.
If, instead, redundancy is low, it is recommended to carefully assess the seismic safety of works of art and buildings located in the critical points[25], with priority for seismic zones 1 and 2.

1.8.3.2.3 Service infrastructures

For the points identified as "critical" upon the fast mode analysis, use may be made of Level 2 SM studies to improve the understanding of the seismic safety of buildings or structures, with priority for seismic zones 1 and 2. For infrastructures falling within seismic zones 3 and 4, the need for the above analyses will be determined on a case-by-case basis.

1.8.3.2.4 Strategic buildings, emergency facilities and other structures

The findings from Level 2 SM studies may be used for the prescribed seismic verification of strategic buildings for civil protection and emergency facilities, with priority for seismic zones 1 and 2 (paragraph 1.9.3.4). For buildings falling within seismic zones 3 and 4, the need for such assessment will be determined on a case-by-case basis.
Given the cost that these analyses involve, it is recommended to carry out simplified assessments of the vulnerability of buildings or structures before passing on to more detailed studies.

1.8.3.2.5 Damage scenarios

Level 2 SM studies permit to refine a given damage scenario. By using differentiated amplification values, differentiated hazards may be taken into consideration for the elements at risk that are present in the investigated area. The consistent utilisation of these data requires the scenario analysis to discretise the investigated area into homogeneous Microzones and, in parallel, to use the available data about vulnerability[26] and exposure at a comparable level of detail. Where this is not possible and the scenario analysis considers the overall municipal territory as an undifferentiated unit, the consequent necessary simplifications may not translate into an actual improvement of results as against approaches that do not consider local effects. It should be stressed that the reference seismic event assumed for the scenarios does not necessarily match the event used in SM studies. For defining the reference seismic event, the following options may be selected:

- the most severe seismic event recorded in the area, with a generally low probability of occurrence;
- the seismic event that mostly contributes to the seismic hazard of the site[27];
- the event causing the most damage.

Technical Datasheet 3.1.12 provides greater insight into damage scenarios for emergency planning*.

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25 Two procedures have been developed to conduct a highly detailed assessment of vulnerability. These procedures are called VC (reinforced concrete) and VM (masonry). The procedures permit to assess the seismic strength of buildings, in terms of both in-plane shear strength (?) and ground acceleration, fully exploiting the data that may be obtained from a not particularly accurate survey and/or from the original project documentation. (ftp://ftp.ingv.it/pro/gndt/Convegni/Convegno_GNDT_2005/Riassunti/Dolce_Dolce.doc)

26 The assessment of vulnerability should not necessarily be made at localised level, but may be simplified by using structurally homogeneous built-up areas of a size compatible with the one of the Microzones.

27 Hazard disaggregation analyses may be conducted for an assigned probability of exceedance. Through these analyses, the magnitude-distance pairs giving the maximum contribution to the hazard of the investigated site may be identified. The events so characterised will be consistent with the Regional hazard analyses on which SM studies are generally founded.

* Not included in the english edition.

1.8.3.3 UTILISATION OF LEVEL 3 SM STUDIES

Where Level 3 SM studies are available, their results may be used for the seismic verification of all buildings or structures identified as "critical" and for which Level 3 investigations are available. The seismic verification is conducted as described in paragraph 1.9.3.4.

1.8.4 IMPLEMENTATION PROCEDURES

1.8.4.1 DATA RELIABILITY ASSESSMENT

The planner will verify the origin of the data and of the SM studies. In the plan documents, he/she will report the reference data of the studies, specifying the names of their authors, the client Administration and their year of publication.

1.8.4.2 DATA REPRESENTATION

The documents of the emergency plan will be integrated with the SM studies. In the emergency plan, the use of Level 1 implies the integration of the seismic risk component into the level of knowledge concerning the risk areas. As to the results of Level 2, in addition to the deliverables already described for Level 1, one level of knowledge should summarise the results obtained from the processing of the damage scenarios.

1.8.4.3 UPDATING SCHEDULES

Generally, the emergency plan should be kept up-to-date on the basis of the progress made in the assessment of the reference event and of an improved understanding of the investigated area.

The preparation of an SM study implies the revision of the existing emergency plan. Any update of SM studies that has impact on the choices of the emergency plan involves the need for updating the plan.

Table 1.8-1 – Utilisation of SM results in emergency planning: fast mode and analytical mode

MS Levels	Modes	Potential elements considered in emergency planning	MS results used in emergency planning	Results
L1	Fast	Emergency areas Road infrastructures Service infrastructures Strategic buildings Emergency facilities Important buildings Productive activities at risk of major incidents Cultural property of particular importance	Stable zones Instability-prone zones Local amplification-prone stable zones	Assessing the adequacy of: Emergency areas Road infrastructures Service infrastructures Strategic buildings Emergency facilities vs. instability-prone zones. Guiding investigations on: Road infrastructures Service infrastructures Strategic buildings Emergency facilities Important buildings Productive activities at risk of major incidents Cultural property of particular importance vs. instability-prone zones. Possible re-siting of the above elements with special emphasis on strategic resources. In the new emergency plans, siting of the above elements preferably in: 1) stable zones, for structural and infrastructural elements; 2) stable zones (even if prone to amplification), for emergency areas
L2	Analytical	Road infrastructures Service infrastructures Strategic buildings Emergency facilities Important buildings Productive activities at risk of major incidents Cultural property of particular importance	Numerical quantifications for instability prone zones, with simplified methods Amplification factors from schedules	Seismic verification of the above elements, which are considered to fall within unstable zones and amplification-prone zones, identified by L1 - Damage scenario assessments
L3	Analytical with local focused investigations	Road infrastructures Service infrastructures Strategic buildings Emergency facilities Important buildings Productive activities at risk of major incidents Cultural property of particular importance	Numerical quantifications of permanent deformation phenomena from numerical simulations Amplification factors or spectra from numerical simulations	Seismic verifications

1.9 Structural and Building Design[28]

1.9.1 GENERAL

National legislation ("Norme tecniche per le costruzioni" – NTC, Building Code)[29] states that the definition of seismic design values must include the evaluation of the effect of local seismic response through specific analyses. These analyses shall indicate the changes that a seismic signal (relative to a rigid site with a horizontal topographic surface – with category A subsoil) undergoes owing to: i) topographic and stratigraphic features of soil deposits and rock masses; and ii) physical and mechanical properties of their constituent materials. Failing such analyses, seismic action may be defined by referring to the categories of subsoil to which the Building Code associates numerical parameters, which modify the response spectra in order to account for the "stratigraphic" effect. The category of subsoil is identified on the basis of the equivalent velocity $V_{s,30}$ of propagation of shear waves within the first 30 m of depth; it is recommended that this velocity be determined directly. Where such determination is not available, classification may be based on the equivalent number of blows of the Standard Penetration Test $N_{SPT,30}$ in predominantly coarse-grained soils and the equivalent undrained strength $c_{u,30}$ in predominantly fine-grained soils. Another parameter, the coefficient S_T, may be used to account for surface morphology (slopes, edges). In low-consistency or liquefaction-prone soils, no simplified approaches are allowed and specific analyses of local seismic response are required[30].

With regard to the design of foundations, the Building Code provides that the following preliminary assessments shall be carried out:

- assessment of site safety in terms of liquefaction and slope stability;
- assessment of the local seismic response of the site.

Additionally, when buildings or structures are to be realised on sloping sites the Building Code requires stability verifications.

Finally, the Building Code provides that the designer shall conduct geotechnical investigations on the basis of an adequately defined understanding of geological conditions, including primary tectonic and lithological features, as well as existing phenomena of soil instability. These investigations shall include the verification of elements that, together with topographic effects, influence the propagation of seismic waves, for example stratigraphic conditions and the presence of a rigid substrate or comparable formation.

28 In this context, the design of buildings or structures refers to structural design, i.e. design aimed at ensuring their mechanical strength and stability, even in the event of fire, as specified in the NTC (Building Code).

29 At the time of writing, the Ministerial Decree of 14 September 2005 is being updated. This legislation will substantially innovate the part concerning seismic design, incorporating additional parts of Eurocode 8 and also parts of the annexes of OPCM 3274/03. The legislation will practically confirm both the importance of the study of local seismic response (local amplification) and, failing such study, the option of accounting for the influence of stratigraphy on local amplification through coefficients depending on the category of subsoil, as well as for the influence of morphology through coefficients depending on morphological characteristics.

30 Similar indications are also contained in Annex 2 of OPCM 3274/03, paragraph 2.4 of which states that "for construction sites and related soils, the occurrence of possible phenomena of slope instability and permanent deformation caused by liquefaction or excessive densification during an earthquake or a surface fault rupture shall be investigated and assessed". Of importance here is the explicit reference to surface faulting.

Hence, the Building Code requires that design activities address aspects that are typical of SM studies. Consequently, these studies will have some objectives in common with those of the design activity. However, their scales will be different: the design activity will cover a specific building or structure and thus a potentially limited area, contrary to what happens in SM studies. Therefore, the study supporting the design activity will usually yield more focused data than those available for SM. The level of study for design activities is established in the Building Code. For SM, it is dependent on the Level, which may be equal to that required for the design activity.

1.9.2 OBJECTIVES

The above infers that the anti-seismic design of buildings or structures may be carried out at a scale and at a level of investigation that differs from those typical of SM studies. Nevertheless, where officially recognised by the local governments involved, an SM study represents an important reference tool enabling the designer to: i) assess the risks of the site where the building or structure is or will be located; and ii) schedule investigations of foundation soils and possible risk mitigation measures. For the purposes of the building regulations governing design activities, the SM study may also represent "a more accurate determination" of one or more aspects (local amplification and permanent deformations), depending on the level at which it is carried out and on eventual Regional regulations. In applying the results of SM to the design activity, the acceptable level of study will be differentiated according to the importance or class of the building or structure[31]: in general, buildings or structures defined as ordinary from the standpoint of their use and economic commitment will require a lower level of study; by contrast, buildings or structures deemed strategic to civil protection and those whose collapse may have severe consequences will need a higher level as applicable legislation imposes greater standards of reliability for strategic buildings or structures. This concept is expressed by the serviceability requirement and by the fact that they must reach the Ultimate Limit State upon events whose probabilities of exceedance are lower than those considered for ordinary buildings or structures. For buildings or structures whose collapse may cause severe consequences in terms of human lives, damage to the environment or to monumental property, the requirements are less strict but higher

31 Since the introduction of the coefficient of importance "I" in 1984, Italian legislation has provided that the seismic action shall be differentiated on the basis of the use of the building or structure, so that: a) buildings or structures considered strategic for civil protection purposes shall continue to function in the immediate post-earthquake period, ensuring relief to the population; b) buildings or structures that are particularly important (number of persons attending them or value or risk to the environment) shall have a lower probability of collapse. These principles evolved into the more performance-based approach of Annexes 2 and 3 of OPCM 3274/2003, as subsequently amended and supplemented. These Annexes require the establishment of design objectives in terms of limit states to be met vs. seismic action levels with assigned probabilities of exceedance, which vary depending on the use of the building or structure. The same Annexes allow for the use of importance factors similar to the protection coefficients specified in Ministerial Decrees issued after 1984. The Building Code issued with the Ministerial Decree of 14 September 2005 adopts the approach of Eurocode 8, considering two importance classes with a useful life of 50 and 100 years and providing for the option of assigning an even higher useful life (200 years) to buildings or structures of exceptional importance. The reference actions to be considered in the design process have a return period equal to 10 times the useful life, thus about 500 years for ordinary buildings or structures, about 1000 for important ones and about 2000 for exceptionally important buildings.
The Building Code being issued requires the seismic action to be commensurate with the reference period (V_R) of the building or structure and with the limit state to be met. The reference period is based on the nominal life of the building or structure (V_N) and on its class of use. V_N is conceptually identical to that specified in the Ministerial Decree of 14 September 2005 and the Eurocode. It is connected with durability requirements and involves 3 values: ≤10, ≥50 and ≥100 years, with the value 10 for provisional buildings or structures. The classes of use are conceptually those that previous legislation associated with differentiated values of coefficients of protection or importance or differentiated probabilities of exceedance of the action. These classes are equal to 4: class I for occasional attendance of persons; class II for ordinary buildings or structures with normal crowding and absence of particular hazardous substances; class III for important buildings or structures with overcrowding and/or hazardous substances; class IV for strategic buildings or structures and industries at risk. The reference period for the seismic action is obtained by multiplying V_N for the coefficient associated with the class of use C_u, ranging from 0.7 (class I) to 2.0 (class IV): $V_R = C_u \times V_N$. V_R may not be lower than 35 years. Therefore, it ranges from 35 to 200 years. The seismic action is commensurate with V_R and with the limit state (L_S) to be met. In practice, V_R, defines the period of observation and the LS is associated with the probability of exceedance of the action to be considered. These probabilities range from 81% for the Serviceability Limit State, 63% for the Damage Limit State, 10% for the Life-Safety Limit State to 5% for the Collapse Prevention Limit State. As a consequence, the return period of the seismic action to be considered in the design process varies from 35 to 3900 years. For ordinary buildings or structures, the return period of seismic action to be considered for the Life-Safety Limit State is equal to approximately 500 years, whereas for strategic buildings or structures it may be equal to 950 or 1900 years depending on V_N.

than those for ordinary buildings or structures. Generally, these buildings or structures require vast investments; therefore, the design activity may rely on resources permitting additional investigations with respect to SM studies.
The Regions will issue procedures for comparing seismic actions[32] described in applicable legislation with those deriving from SM studies.
All levels of SM studies lend themselves to being utilised, albeit to a different extent.
The implementing party and the designer should interact to assess the reliability of data, calculations and results.

The following paragraphs describe the utilisation of SM studies for the above-mentioned types of buildings or structures:

- new ordinary buildings or structures;
- existing ordinary buildings or structures;
- new strategic buildings or structures;
- existing strategic buildings or structures.

1.9.3 UTILISATION OF SM STUDIES

1.9.3.1 NEW ORDINARY BUILDINGS OR STRUCTURES

In the case of new ordinary buildings or structures, the *Map of Seismically Homogeneous Microzones* (Level 1) offers some elements of immediate use:

- in stable zones (paragraph 1.6.3.1.2), after checking in fast mode[33] whether the map data respect the situation of the construction site and after completing limited investigations, the reference subsoil category will be determined; this category will usually be A, or B if an altered layer or intense and pervasive fracturing cause the mechanical properties of the subsoil to fall under this category;
- in local amplification-prone stable zones, an understanding of stratigraphic conditions may guide the choice of eventual investigations to determine the subsoil categories required by law in terms of thickness and lithological composition;
- instability-prone zones require investigations from the early stages of the design process.

The *SM Map* (Level 2) may be organically employed as part of the design activity:

- in stable zones, after checking whether the features of the construction site match those reported in the map and after conducting limited investigations, the site will be assigned to subsoil category A, or B if an altered layer or intense and pervasive fracturing place its mechanical properties under this category[34];
- in local amplification-prone stable zones, appropriate schedules may be used, provided that the fea-

32 As amended to account for local amplification effects using subsoil categories and topographic coefficients.

33 At any rate, the design of a building or structure requires investigations to mechanically characterise the soils and to size the foundations. These investigations may offer sufficient elements to determine whether the site corresponds to the features of the homogeneous microzone and thus make a choice between subsoil categories A and B.

34 In stable zones associated with category B, the appropriate schedules may be used for the design activity, provided that the features of the construction site are consistent with the basic assumptions adopted in the preparation of the same schedules.

tures of the construction site are consistent with the basic assumptions adopted for the schedules. Generally, based on these assumptions, the subsoil may be equated with a sequence of roughly planar-parallel layers, with moderate morphological irregularities. For these conditions, the Region may adopt different procedures according to its own regulatory-legislative framework. Based on the comparison between the seismic action inferred from the schedules with that obtained using the subsoil category and related spectrum as per applicable legislation, the following options may be chosen:
  - using the more severe action between the two;
  - referring the final assessment of the action to be used to the designer;
  - require specific and additional investigations;
- in instability-prone zones Level 2 does not generally offer enough data to design a new building or structure; thus, safety conditions will be verified after conducting focused investigations at a level comparable with Level 3.

The *Detailed SM Map* (Level 3) may be used during design in all cases where detailed investigations correspond with the minimum values established by applicable legislation.

1.9.3.2 EXISTING ORDINARY BUILDINGS OR STRUCTURES

In the case of existing ordinary buildings or structures, the *Map of Seismically Homogeneous Microzones* (Level 1) offers different elements of immediate use:
- in stable zones, after checking in fast mode whether the map data actually match the situation of the site of interest and after carrying out investigations of limited extent or using existing data, the subsoil reference category will be assigned; this category will be A, or B if an altered layer or intense and pervasive fracturing cause the mechanical properties of the subsoil to fall under this category;
- in local amplification-prone stable zones, an understanding of stratigraphic conditions may guide the choice of eventual investigations to determine the subsoil categories required by law in terms of thickness and lithological composition; moreover, for works involving buildings or structures that do not increase loads on foundations, that do not worsen slope conditions and in the absence of instabilities ascribable to soil failure, it is possible that slope stability verifications may not be required[35].
- in instability-prone zones, safety conditions will be verified after conducting focused investigations at a level comparable with Level 3.

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35 This verification requires knowledge of data regarding areas outside the construction site, whose stability may be sufficiently guaranteed by the findings of the SM study, given its broader scope. On the other hand, the Ministerial Decree of 16 January 1996 and the related Circular Letter no. 65 from 1997 stipulate that works on foundation structures and related verifications may be omitted, provided that all the requirements established in the legislation are simultaneously met. These requirements are met - and thus entail a successful verification of the efficiency of the existing building or structure - when the designer provides a reasoned opinion after ensuring that no (present and past) instabilities exist and that the retrofitting/improvement project does not significantly alter the structural layout and the loads on the foundations. If the geological bedrock outcrops or occurs on a slope with gradients above 15°, if the SM study has not revealed any instability phenomena, if the works to be carried out do not alter existing conditions and if no instabilities connected with permanent soil deformations have appeared, then the principle established by the legislation for foundations may reasonably be extended to the slope.
The Ministerial Decree of 11 March 1988 specifies that "in case of small buildings or structures falling within already known zones, the site and lab investigations on foundation soils may be reduced or omitted, provided that the soils are characterised on the basis of data from previous investigations conducted on similar soils and nearby areas. In this case, the sources for the physical-mechanical classification of the subsoil shall be specified". In this case, the data supplied by the SM study may be sufficient to fulfil the requirements of the legislation.

The *SM Map* (Level 2) may be organically employed in the activity of planning/designing seismic retrofitting or controlled improvement projects/works:

- in stable zones, after checking whether the project site characteristics match those reported in the map and after carrying out investigations of limited extent, the site may be associated with subsoil category A, or B if an altered layer or intense and pervasive fracturing cause the mechanical properties of the subsoil to fall under this category[36];
- in local amplification-prone stable zones, appropriate schedules may be used for design, provided that the project site is consistent with the basic assumptions underlying the preparation of the schedules. In general, on these assumptions, the subsoil may be equated with a sequence of roughly planar-parallel layers, with moderate morphological irregularities. For these conditions, the Region may adopt different procedures, in line with its own regulatory-legislative framework; these procedures will not necessarily be similar to those issued for the construction of new buildings or structures[37]. Based on the comparison between the seismic action inferred from the schedules and that of the subsoil category and related spectrum as per applicable legislation, the Region may alternatively
  - require the use of the more severe action between the two;
  - refer the final assessment of the action to be used to the designer;
  - require specific and additional investigations.
- in instability-prone zones, when the safety conditions determined by the SM study fall within the limits of legislation governing existing buildings or structures, if the project does not alter the loads on foundations and if no instabilities induced by these loads are present, the Region may
  - allow the use of the SM indications;
  - refer the choice of whether the SM study is to be used or not to the designer;
  - require specific investigations.

If the SM study indicates that the safety conditions fall outside the limits specified in legislation governing existing buildings or structures, investigations comparable with those of Level 3 will be needed.

The *Detailed SM Map*(Level 3) may be used to plan or design projects or works in all the situations in which the detailed investigations correspond to the minimum ones prescribed by applicable legislation.

1.9.3.3 NEW STRATEGIC BUILDINGS OR STRUCTURES

When designing strategic buildings or structures for civil protection purposes or important buildings or structures, reliance will be made on levels of knowledge comparable with those of Level 3 SM, at least in low (zone 3), medium (zone 2) or high-seismicity zones (zone 1). For very low-seismicity zones (zone 4), the criteria for the use of SM studies are those described in the previous paragraphs in connection with new ordinary buildings or structures.

36 In stable zones associated with category B, appropriate schedules may be used for design, provided that the characteristics of the construction site are in line with the basic assumptions underlying the preparation of the same schedules.

37 Both the Ministerial Decree of 16 January 1996 and OPCM 3274/2003 recognise that the safety levels of existing buildings or structures may be different from those established for new buildings or structures. OPCM 3274/2003, Annex 2, Chapter 11 stipulates that "taking into account the specificities of the types of buildings or structures in their own territory, the Regions may provide for controlled vulnerability improvement projects by reducing the seismic protection levels by up to 65% of the level prescribed for new buildings and structures and thus the extent of the seismic actions to be considered for the various limit states, as well as the number of limit states to be considered".

Where the construction site has already been covered by an SM study, the findings from this study will be used to optimise the required investigations and as elements of comparison.

1.9.3.4 EXISTING STRATEGIC BUILDINGS OR STRUCTURES

In case of seismic retrofitting, controlled improvement or seismic safety assessments, the levels of knowledge and the use of SM studies are the same as those established for new strategic buildings or structures. In the case of projects aimed exclusively at the seismic improvement of sites that have already been covered by SM studies, these studies may be used provided that they have been developed at Level 2 or higher.

1.9.4 IMPLEMENTING PROCEDURES

1.9.4.1 DATA RELIABILITY ASSESSMENT

The designer is responsible for any data autonomously collected from bibliographic references and ad-hoc investigations. When using the data provided by the SM study, the designer is responsible for ensuring that the situation of the construction site matches that of the homogeneous zone described by the SM study. Any differences will be reported, by documenting them according to regional standards, to the party responsible for the study, to the project oversight body and to the validating party.

1.9.4.2 IMPLEMENTATION SCHEDULES

The Region will issue rules and procedures for applying the results of SM studies to on-going design or construction processes, eventually considering the different typologies of buildings or structures.

1.9.4.3 CALCULATIONS AND RESULTS

The representation of the results of the design process, which interact with or make use of the results of SM studies, will reconcile the requirements specified in the technical standards and by regulatory bodies with the data available from SM studies. The project will clearly indicate i) the SM document of reference for each specific aspect (local amplification and permanent deformations), ii) the point taken into consideration; and iii) the possible criteria of application to the specific site. The report on foundation conditions must contain excerpts from the SM study pertaining to the site, identifying the homogeneous zones within which the site falls and highlighting the lithostratigraphic cross-sections of interest and the specific investigations carried out to ensure that the observed situation conforms to the classification of the homogeneous zone in the SM[38].

38 Notwithstanding the investigations needed for the design activity under the applicable standards (mechanical classification of soil, etc.).

UNIVERSITY OF TRIESTE
AGREEMENT NUMBER 2723

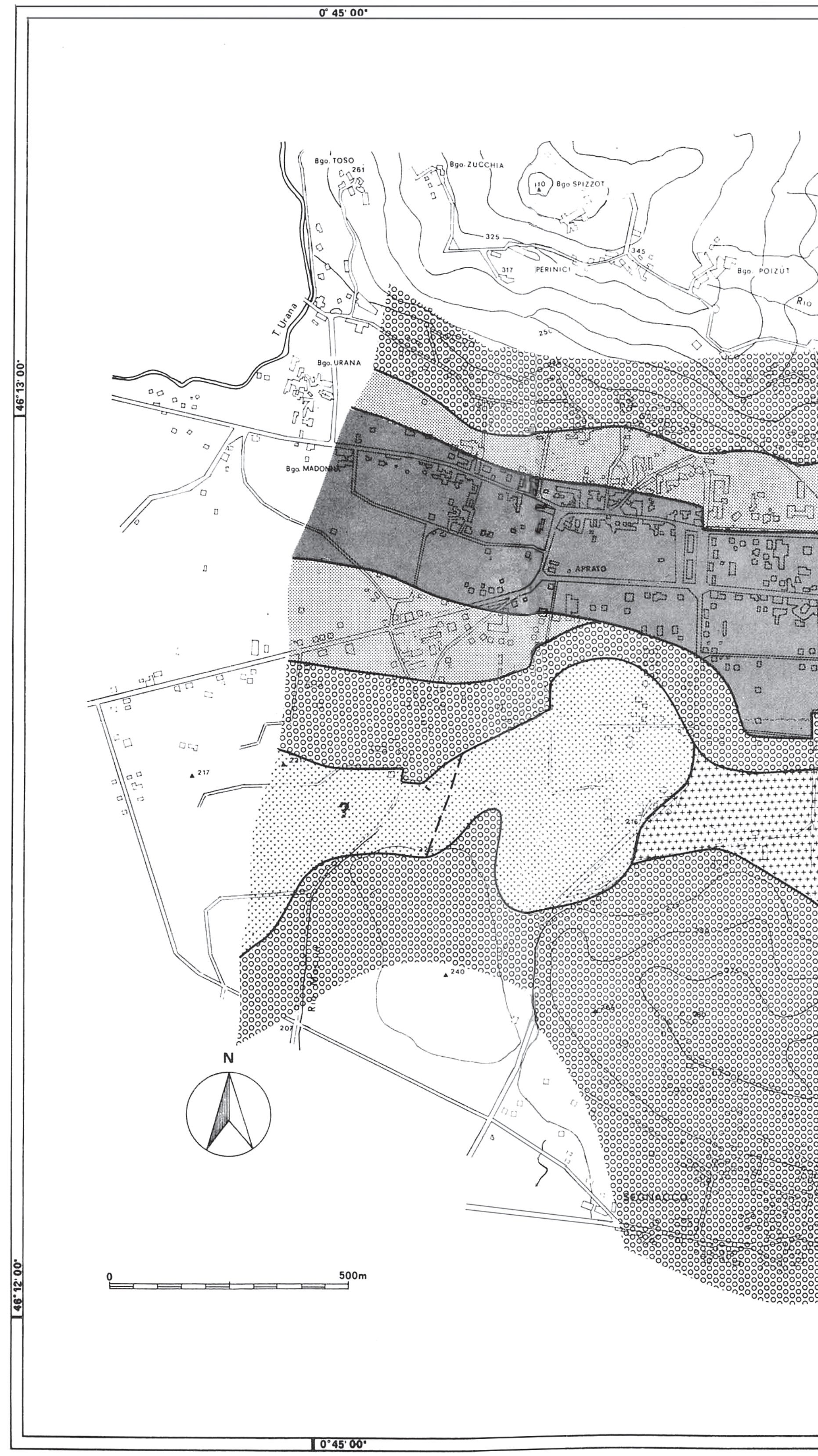
MICROZONATION STUDY OF THE TARCENTO AREA

MICROZONATION PROPOSAL
Annex 16 Trieste, December 1978

LEGEND

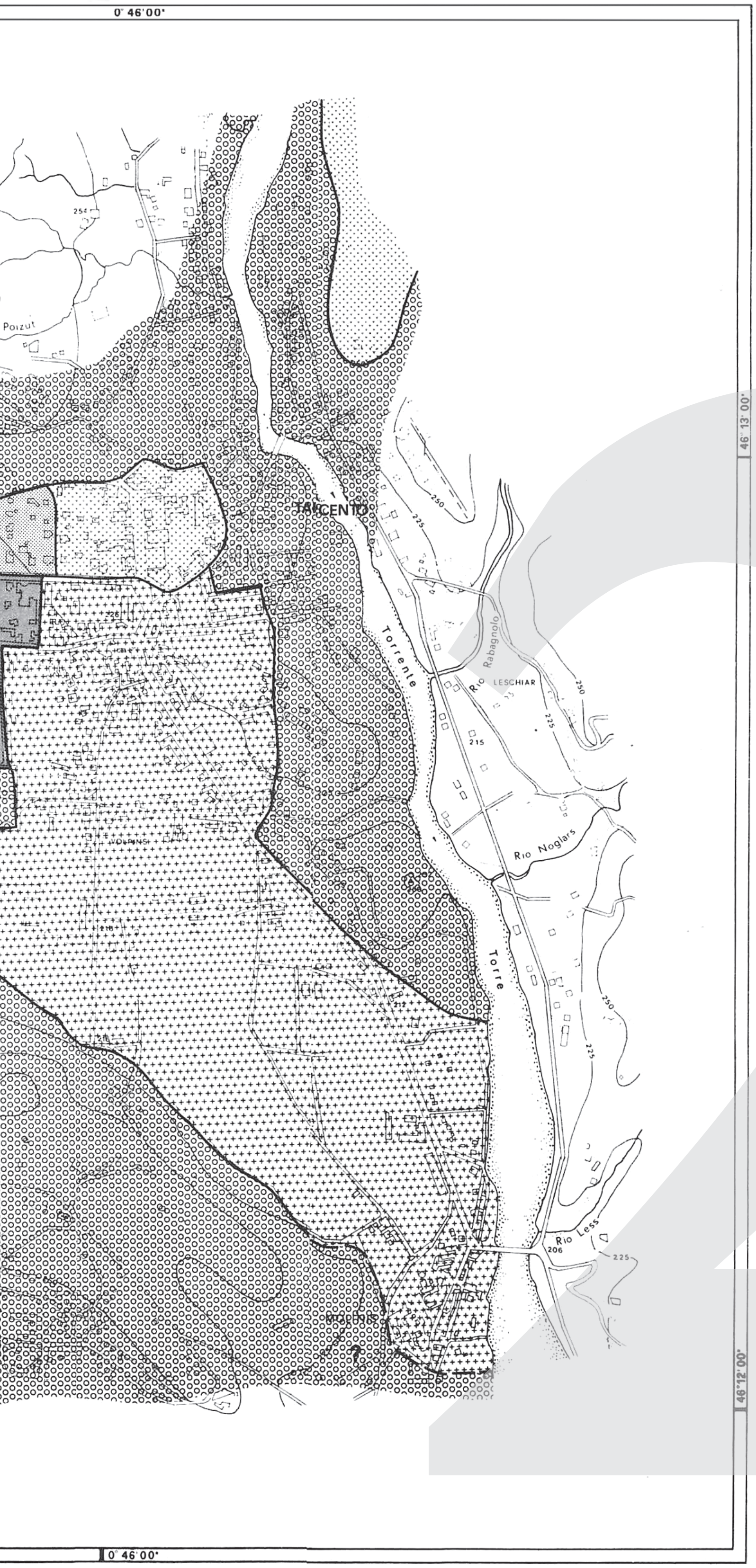
	ε_1	ε_2
zone A	1,0	1,0
zone B	1,6	1,0
zone C	1,0	1,3
zone D	1,3	1,3
zone E	1,0	1,6

local coefficients of increase for the design seismic actions



Guidelines

2



Microzonation study of the Tarcento (UD) area.
(CNR – PFG, 1986).

2.1 Procedures for Conducting Investigations

2.1.1 GENERAL NOTES

In-situ and laboratory investigations help to define the model of the subsoil, based on local lithotechnic units, their stratigraphic and geometric relations and their typical physical-mechanical parameters. The model makes it possible to assess local phenomena of amplification phenomena in stable zones and eventual phenomena of instability.

The investigations required to construct a model of the subsoil may be classified as follows:

- geological, geomorphological and lithological-technical surveys;
- geophysical investigations;
- geotechnical investigations
  - in-situ investigations;
  - laboratory tests.

The Appendix (Chapter 3.4)* provides detailed technical instructions on how to conduct geological, geophysical, geognostic and geotechnical investigations, collect related data and present their results. The following two paragraphs provide information and indications of a more general nature.

2.1.2 TYPES OF INVESTIGATIONS

The model of the subsoil will be based on:

- a topographic map of the investigated area; for an SM study, the scale of the map must be at least 1:10,000;
- thematic maps of the investigated area: geological, engineering-geological, hydrogeological and geomorphological maps resulting from careful field surveys;
- lithostratigraphic and geotechnical data, collected by means of boreholes and lab tests;
- geophysical data defining the propagation velocity of seismic waves inside soils and the geometry of lithotechnic units.

Different tests are available. The most common ones are:

- Standard Penetration Tests (SPT) are used to obtain quantitative values of soil penetration resistance. A 63.5 kg hammer is dropped from a height of 76.2 mm (European standard) onto a set of rods with a cylindrical sampler in their terminal part. The sampler is driven into the soil for 15 cm; afterwards, the number of blows needed to penetrate into the soil by another 15 + 15 cm is recorded; this value represents the penetration resistance.
- Cone Penetration Tests (CPT) are carried out by driving a cone tip into the soil at a constant rate of 20 mm per second. The instrument consists of a tip and of a friction sleeve, which measure the tip resistance (q_c) and the sleeve friction (F_s), respectively. The ratio between these two values permits an estimate of the nature of the soil being crossed (fine- or coarse-grained). With appropriate correlations, the tip resistance may be used to estimate mechanical properties and approximately reconstruct the stratigraphy of the subsoil.

* Not included in the english edition.

- Vane Shear Tests employ an apparatus consisting of a four-blade stainless steel vane attached to a steel rod that is pushed into the ground. A gauge mounted on top of the device measures torque. The blades are driven into the bottom of the borehole to a depth of 50 cm and rotated until the soil fails along a cylindrical shear surface. The values of the in-situ undrained shear strength (c_u) may be obtained from the stress required to reach failure, i.e. the torsional moment or torque (M_t).
- Dilatometer Tests (DMT)[39] are conducted by vertically driving a blade-equipped testing instrument into the soil (static thrust), inflating a circular membrane located on one side of the instrument with pressurised gas and measuring the corresponding pressures at two predetermined levels of deformation of the membrane. The thrust instrument may be a static penetrometer (20 t of effective thrust), equipped with a set of thrust rods or with the thrust instrument of a drilling probe. The dilatometer assembly includes: a) dilatometer blade (95 x 200 x 15 mm) with a lateral metal membrane, which may be expanded by 1.1 mm at its centre; b) measuring station; c) electropneumatic cable connecting the dilatometer with the measuring station; d) nitrogen gas bottle with pressure reducer. The dilatometer is vertically thrust into the soil, stopping the penetration every 20 cm for taking measures. After reaching the testing elevation, penetration is stopped and thrust is applied to the rods. Gas is fed to the membrane and an electropneumatic station at the surface measures the following values: a) pressure at which the membrane detaches (read-out A – the signal stops); b) pressure needed to expand the centre of the membrane by 1.1 mm (read-out B – the signal starts again); c) where needed, the pressure value C, expressing the pressure exerted on the membrane when, upon gas discharge, the same membrane closes onto the rest position A, reactivating the sound signal.

Lab tests will identify:

- index properties of the sample: grain size, water content (w), plasticity index (I_p), natural weight of the unit of volume (γ_n), relative density (D_r);
- static mechanical parameters – which define the soil strength in terms of friction angle (ϕ), cohesion intercept in terms of effective stresses (c') and the undrained strength in terms of total stresses (c_u) – and soil deformability characteristics, which are defined by Young's modulus (E), Poisson's coefficient (ν) and by the oedometric modulus (E_d);
- dynamic mechanical parameters, which describe: the behaviour of the soil undergoing cyclical stresses, thus water overpressure possibly generated (ΔU); the damping factor (D), which summarises energy dissipation; and the dynamic shear modulus at low deformation (G_0). The shear modulus (G_0) may also be obtained from geophysical tests and appropriate correlation formulas.

The most important geophysical tests to define the velocity of propagation of seismic waves inside soils and help reconstruct the geometry of deep bodies are as follows.

39 Reference standards/legislation for this test: ASTM (2001) "D 6635-01 Standard Test Method for Performing DMT", Book of Standards Volume 04.09; CEN-Eurocode 7 (1999) - "Flat dilatometer test (DMT)", Part 3, Section 9.

- Seismic refraction tests use a set of geophones to record the time of arrival of the first seismic wave generated by an energy source. The placement of the geophones and sources at the surface allows for the obtainment of linear seismic profiles.
- Down-hole and cross-hole tests are seismic investigations that require specially equipped boreholes to measure the transmission time of seismic waves in the soil. In-hole geophones record the arrival of artificially generated seismic waves. In down-hole tests, a single borehole is used and the wave source is at the surface; in cross-hole tests, the boreholes are generally two: one for the geophone and one for the source. The velocities of shear waves (V_s) and pressure waves (V_p) may be obtained by identifying and interpreting the arrival time of S and P waves.
- Seismic dilatometer tests (SDMT) derive from the combination of conventional dilatometer tests with an excitation system at the surface and a geophone inserted into the blade. The array for this test is practically similar to that employed in a down-hole test but without the borehole; therefore, the propagation velocity of shear waves (V_s) may also be measured.
- ESAC or SASW tests measure the velocities of surface waves, from which the velocity of S waves is derived.
- Vertical electric soundings (VES) and horizontal electric soundings (HES) measure soil resistivity, from which the geometry of deep rock sequences may be defined.
- Radar soundings define the geometry of the rock sequences at depth.
- Microtremor tests measure the period and amplitude of soil vibrations (in the range of 10^{-4} -10^{-2} mm) to which our planet is constantly subject (environmental seismic noise or microtremor).

2.1.3 INDICATIONS AND RECOMMENDATIONS

The investigations must be adequately organised to optimise times and costs.
The Ministerial Decree of 21 January 1988 stipulates that "the scale of investigation shall be commensurate with the size, type, structural characteristics and importance of the building or structure, with the complexity of the subsoil and with the level of knowledge of the investigated area". The Decree provides general indications for the design of buildings or structures, but only a short description of area-wide investigations.

In accordance with the National Building Code:

Design choices shall take into account the expected performance of buildings or structures, the geological characters of the site and environmental conditions (...). Design analyses shall be based on engineering-geological models inferred form specific investigations and tests that the designer shall define after selecting the type of building, structure or project, as well as construction or implementation procedures (...). Depending on the type of building, structure or project and on the complexity of the geological setting, specific investigations shall be carried out in view of reconstructing the geological model in a documented way. The model shall represent a reference tool that the designer shall use to tackle geotechnical issues and define the program of geotechnical investigations (...) The geotechnical investigations shall be planned on the basis of the type of building, structure and/or project, concern the significant volume referred to in § 3.2.2 and permit the definition of the geotechnical models of the subsoil required for the design activity.

For seismic design, the Building Code provides that:

The designer shall prepare the geotechnical investigations on the basis of an adequately defined geological setting, including its main tectonic and lithological features, as well as existing instability phenomena. The investigations shall verify the factors that, together with topographic effects, affect the propagation of seismic waves, such as stratigraphic conditions and occurrence of stiff bedrock or of a similar formation.

The physical-mechanical characterisation of soils and the selection of the most suitable investigation resources and procedures shall take into account the type of geotechnical system and the method of analysis adopted upon verifications.

In the case of buildings or structures for which advanced analytical methods are planned to be used, cyclical and dynamic lab tests shall also be conducted, provided that a collection of undisturbed samples is technically feasible. At any rate, the geotechnical characterisation of soils shall at least permit the classification of the subsoil in accordance with the criteria described in § 3.2.2. The geotechnical description must evaluate the dependence of stiffness and damping on the level of deformation.

Also in this case, the legislation is more focused on investigations for the design of specific buildings or structures than on area-wide investigations.

However, the planning of investigations is an iterative process: on one hand, the data gradually collected raises new issues whose resolution in turn requires new investigations; on the other hand, very often, problems of cost and the availability of equipment and expert professionals make it necessary to conduct investigations on a step-by-step basis.

How accurately the subsoil characteristics are to be verified is an issue to be decided by comparing goals, available resources and timescales. In general, investigations will be commensurate with the complexity of the problem at stake and of the software models employed. Finally, all studies must be associated with an evaluation of parameters of uncertainty.

As to the average areal density of the points to be investigated, indicative values may be inferred form literary sources (AGI, 1977 and 2005: 0.1-2 tests/ha). The highest values will apply to zones with the highest level of exposure, to those with the least compact and consistent soil covers and to those with the highest variability of characteristics.

Sites to be investigated will be selected on the basis of existing knowledge and ease of access, giving preference to soils more susceptible to local phenomena.

The depth to be investigated will be based on different environmental factors. Generally, the depth of the bedrock will be estimated through geophysical surveys and boreholes. Indicatively, a selection of boreholes should reach a depth of 50 m.

The above values do not concern unstable zones, where the points to be investigated should be very close to each other and the investigations should reach the depth needed to identify the geometry and characters of formations with poor mechanical properties.

2.2 Procedure for Drawing up the Map of Investigations

The map of investigations will be prepared for each of the three levels of SM (Chapter 1.6):
- for Level 1, existing investigations will be indicated;
- for Levels 2 and 3, new tests will be indicated together with existing investigations.

At all Levels, areas where additional investigations are considered to be important or absolutely necessary will be mapped.

2.2.1 GOALS

The map of investigations will show the location and type of investigations.
The distribution of investigations over the study area will help:
- identify areas with lower numbers of investigations and plan additional investigations;
- allow for the preliminary assessment of the quality of the study: the higher the number of investigations and data, the more reliable the interpretation and results.

2.2.2 MAPPING SCALE

As in the case of SM studies, maps must be produced at a scale of 1:10,000 or higher.
Available investigations will be collected for an area wider than the study area, so as to understand and completely document both the preliminary geological model and the natural phenomena that may involve the area or have an impact on SM.

2.2.3 MAPPING OF INVESTIGATIONS

The investigations will be mapped using different symbols for each type.
Considering the importance of the thickness of covers, of altered layers and of the depth of the bedrock in assessing the local seismic response, the map should clearly highlight the position of tests that have reached bedrock.

The data from in-situ tests and sampling points (existing and new) will be organised into a database and georeferenced on a regional technical map through a GIS.

Pending technical specifications on the georeferenced database of investigations, a tentative and non-exhaustive list of investigations types for preliminary classification is reported below:

GEOTECHNICAL INVESTIGATIONS

S Continuous-coring borehole
S_d Destructive-drilling borehole
S_c Borehole from which samples have been collected
S_p Borehole with piezometer
S_i Borehole with inclinometer
SPT Standard Penetration Test (in-hole)
CPT Static Cone Penetrometer Test with mechanical cone
CPTE Static Electric Cone Penetrometer Test
CPTU Static Piezocone Penetrometer Test
DPH Dynamic Probing with Heavy Penetrometer
DPL Dynamic Probing with Light Penetrometer

DMT Dilatometer Test
PMT Pressuremeter Test
VT Vane Test
PLT Plate Load Test
SDMT Seismic Dilatometer Test

P_a Water well
P_i Hydrocarbon well
T Trench or borehole
T_v Drilling

GEOPHYSICAL INVESTIGATIONS

S_r Seismic refraction profile
Sl Seismic reflection profile
3D 3D seismic investigation or seismic tomography
DH Down-Hole seismic test
CH Cross-Hole seismic test
UH Up-Hole seismic test
ReMi Refraction Microtremor test
SCPT Seismic Cone Penetrometer Test
N Noise measurement
SASW Spectral Analysis of Surface Waves
MASW Multichannel Analysis of Surface Waves
VES Vertical Electric Sounding
HES Horizontal Electric Sounding
SR Soil resistivity profile

2.3 Procedure for Drawing up the Map of Seismically Homogeneous Microzones (Level 1)

The Level 1 *Map of Seismically Homogeneous Microzones* (hereafter the "Map") represents the fundamental document at this level of study. The Map is to be developed preferably at a scale of 1:5,000 – 1:10,000.
This section describes the following topics:

- demarcation of areas to be investigated;
- selection of basic data;
- legend and map field;
- identification of significant geolithological sections.

2.3.1 DEMARCATION OF AREAS TO BE INVESTIGATED

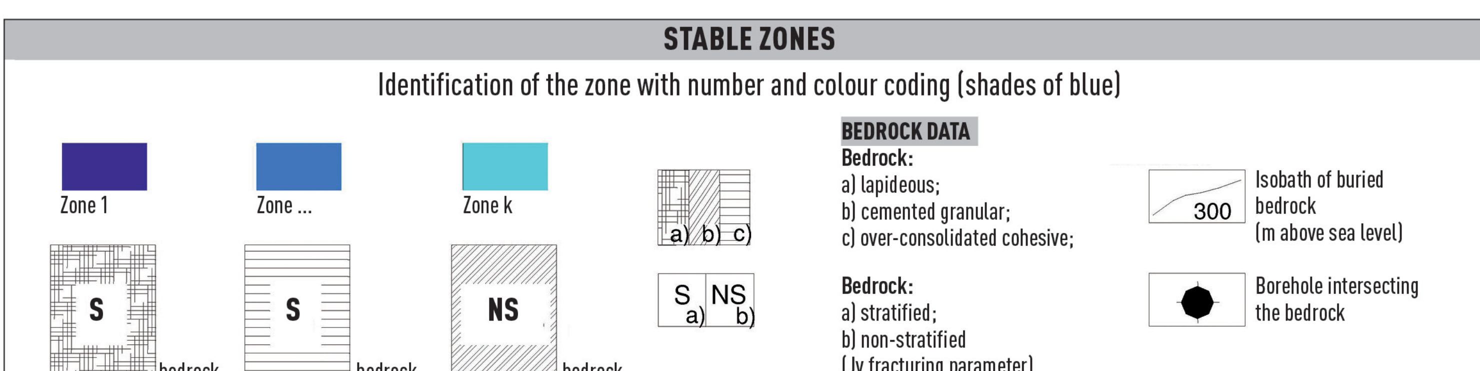
The areas to be mapped are identified jointly by the implementing party and the proposing party of SM studies (usually, persons in charge of land planning and emergency planning). However, the agreed demarcation will be provisional and subject to change during mapping, depending on the geological and geotechnical issues that may be identified. In particular, the study area must be extended to include the zone of influence of geological phenomena that may affect the area to be microzoned.

2.3.2 SELECTION OF BASIC DATA

In addition to available basic maps, basic data that may be used include:

a. geological and geomorphological maps at a scale of 1:5,000 – 1:10,000;
b. lithotechnic map at a scale of 1:5,000 – 1:10,000;
c. lithostratigraphic logs inferred from borehole data;
d. geolithological sections on the basis of data inferred from a., b. and c.;
e. hydrogeological instability maps (e.g. "IFFI" Project, provincial hydrogeological instability plans, Basin Boards' plans);
f. map of investigations.

2.3.3 LEGEND AND MAP FIELD



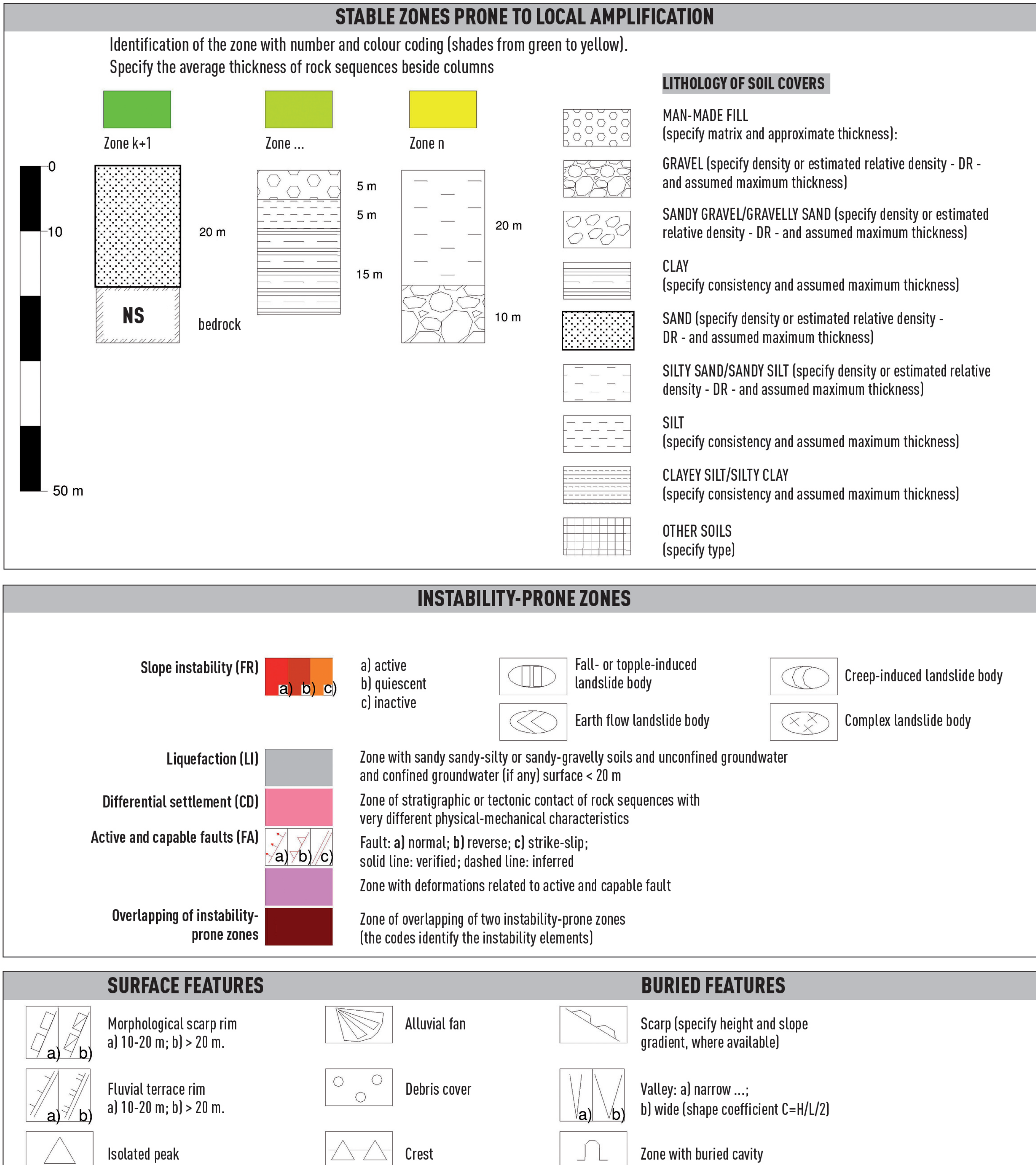


Figura 2.3-1 - Legend of the *Map of Seismically Homogeneous Microzones.*

The Map is constructed to obtain an adequate level of detail, so as to reach the following objectives:

- characterisation of the geological bedrock;
- characterisation of soil covers;
- reconstruction of areas with a potential to develop permanent deformations in the event of an earthquake;
- definition of surface and buried geomorphological features, which are particularly important for seismic problems.

These objectives may be pursued by distinguishing between three types of zones in the map field and using symbols to indicate surface and buried features (Figure 2.3-1):

a. stable zones, in which no effects of any nature are assumed, except for ground motion (dependent upon energy and distance from the event).

These zones are defined by geological bedrock outcroppings with a flat or slightly inclined morphology (slopes with a gradient of roughly less than 15°)[40].

Based on available literature, prior knowledge of the study area and collected data, the implementing party will identify those zones most likely to present a value of $V_s \geq 800$ m/s.

The description of this zone must include some data about the bedrock:

- type: lapideous, cemented granular, over-consolidated cohesive, alternating rock sequences, e.g. flyschoid deposits (differences highlighted using dotted hatching);
- stratification: yes/no (difference highlighted with S and NS indexes);
- fracturing: difference based on the parameter J_v (note that zones with $J_v > 10$-15 might not be classified as stable zones, but as stable zones prone to local amplification);
- depth of zones where the bedrock does not outcrop (with isobaths);
- location of boreholes intercepting the bedrock.

The stable zones will be differentiated on the basis of their type, stratification and fracturing.

The zones of this category will be colour coded in shades of blue with a sequential code identifying individual areas (from 1 to *k*).

Highly fractured belts (e.g. mylonitic belts near tectonic lineaments) will be highlighted (with an appropriate red dotted hatch on white background and with no identification code).

b. stable zones prone to local amplification, in which seismic motion amplification is expected as an effect of local lithostratigraphic and morphological conditions.

These zones feature soil covers, bedrock alteration covers, highly fractured bedrock or bedrock with a shear wave propagation velocity of $Vs < 800$ m/s. The thickness of these soils should exceed 5 m.

Local rock sequences will fall under the following categories:

1. anthropic fill, specifying the matrix and approximate thickness;

40 The Building Code and Eurocode 8 provide that topographic effects may be neglected for slopes with an average gradient of less than 15°.

2. gravel, specifying the density or relative density - D_R - and the assumed minimum and maximum thickness;

3. sandy gravel – gravelly sand, specifying the density or the relative density - D_R - and the assumed minimum and maximum thickness;

4. sand, specifying the density or relative density - D_R - and the assumed minimum and maximum thickness;

5. Silty sand – sandy silt, specifying the density or relative density - D_R - and the assumed minimum and maximum thickness;

6. silt, specifying the consistency and the assumed minimum and maximum thickness;

7. clayey silt – silty clay, specifying the consistency and expected minimum and maximum thickness;

8. clay, specifying the consistency and assumed minimum and maximum thickness;

9. alluvial deposit with mixed or indistinct grain size distribution, specifying the assumed minimum and maximum thickness;

10. debris cover (on slope with gradient < 15°) with mixed or indistinct grain size distribution and the assumed minimum and maximum thickness;

11. altered or intensely fractured bedrock cover, specifying the assumed minimum and maximum thickness;

12. bedrock with $V_S < 800$ m/s;

13. other soils, specifying the type and assumed minimum and maximum thickness.

Stable zones prone to local amplification will be reported in the map field and each must uniquely match a lithological sequence reported in the legend.

The most representative average thickness will be reported beside each rock sequences (obviously considering the minimum and maximum thickness shown in the legend). The depth of the geological bedrock will be reported for those zones where it is available. Lithological sequences will be mapped in scale to the extent possible.

The microzones of this category will be colour coded in shades from green to yellow.

Stable zones prone to local amplification will have a sequential code from k+1 to n.

c. instability-prone zones, in which the expected and dominant seismic effects may be ascribed to permanent ground deformations (obviously, phenomena of ground motion amplification are not excluded). The zones will identify four categories of deformation effects:

- slope instabilities (sequential code, identifier for the individual areas, from FR_1 to FR_n).

They will be distinguished by type of landslide:

- fall- or topple-induced
- creep-induced
- earth flow
- complex landslide

and by activity:

  - active
  - quiescent
  - inactive

- liquefaction (LI_1-LI_n).

Zone with sandy, sandy-silty or sandy-gravelly soils and unconfined groundwater and confined groundwater (if any) surface < 15 m

- active and capable fault (FA_1-FA_n) (specify the area with fault-induced deformations).

These zones will be distinguished by fault type:

  - normal
  - reverse
  - strike-slip

and by:

  - verified
  - inferred

- differential settlements (CD_1-CD_n).

Zone of stratigraphic or tectonic contact of rock sequences with very different physical-mechanical characteristics.

The overlapping of two instability-prone zones will be marked using both codes.

d. surface features

- morphological scarp rim
  - 10 - 20 m
  - > 20 m
- Fluvial terrace rim
  - 10 - 20 m
  - > 20 m
- isolated peak
- crest
- alluvial fan
- debris cover

e. buried features

- scarp

  specify height and slope gradient
- valley
  - narrow valley C > 0.25
  - wide valley C < 0.25

C shape coefficient (C=h/l)

where *h* is the thickness of the alluvial cover and *l* is its semi-amplitude.

- zone with a buried cavity.

2.3.4 IDENTIFICATION OF SIGNIFICANT GEOLITHOLOGICAL SECTIONS

The geological-technical sections that may be used to develop preliminary considerations about local seismic hazard levels will be reconstructed on the basis of: geological and structural characteristics; morphology; relations between cover deposits and bedrock; and distribution of the study areas. Particular emphasis will be placed on potential causes of seismic amplification, for which 1D and 2D sections will have to be identified and subjected to numerical modelling.

With regard to the effects of seismic stresses, the main geological and geomorphological aspects to be considered in the sections may be summarised as follows:

a. amplification due to topographic and morphological effects. These are morphological discontinuities that may amplify the ground motion connected with the focusing of seismic waves, e.g.:

- slopes with a gradient > 15° and difference in elevation of more than 30 m;
- terrace edges or rim areas ($H > 10$ m);
- thin rocky crests (lesser width at the crest than at the base and average slope gradient > 30°)

b. amplification due to lithological effects. Amplification is related, first of all, to differences of seismic stiffness between the bedrock and the cover and, subordinately, to geometric configuration, with consequent focusing of seismic waves: fluvial valleys, alluvial fans, debris covers, very fractured rock masses.

c. Amplification due to buried morphologies. In this case, amplification is generated by a rocky bedrock with a very irregular buried morphology (e.g. presence of palaeo-ice-streambeds). This may also produce phenomena of focused seismic waves.

The Annex provides some examples of this type of map*.

* Not included in the english edition.

2.4 Procedures for Drawing up the SM Map

The *Level 2 SM Map* is the fundamental document of this level of study. The Map is to be preferably drawn up at a scale of 1:5,000 – 1:10,000.

This section describes the following topics:

- basic data;
- legend and map field.

STABLE ZONES – Blue colour-coded			
	FA	***FV***	**Information about stable zones**
	1	1	Note that zones with a geological bedrock having $Jv \rightarrow$ 10-15 or V_s < 800 m/s might not be classified as stable zones

STABLE ZONES PRONE TO LOCAL AMPLIFICATION – Red-to-yellow colour-coded			
	FA	***FV***	**Information about stable zones prone to local amplification**

INSTABILITY-PRONE ZONES – Green colour-coded, instability code and sequential number from 1 to n		
	Quantitative parameters	**Information about instability-prone zones**
Slope instability (*FRT_x*, *FRR_x*)	*Soils (T): maximum displacement (cm)* *Rock (R): maximum distance between blocks (m)* e.g. FRT_1 = 20 cm ... eg. FRR_n = 150 m	
INSTABILITY-PRONE ZONES - Green colour-coded, instability code and sequential number from 1 to n		
Liquefaction (*LI_y*)	*Liquefaction potential LI* e.g. LI_1 = 7 ... e.g. LI_n = 18	
Differential Settlement (*CD_z*)	(none)	
Active and Capable Faults (*FA_w*)	(none)	
Overlapping of instability- prone zones and local amplification-prone zones	The background colour identifies the local amplification-prone stable zone (from yellow to red), whereas the instability-prone zone is identified using superimposed oblique green shading lines, from left to right and from bottom to top, the code and the sequential number.	

Figure 2.4-1 – *SM Map Legend.*

2.4.1 BASIC DATA

The map shows the results of analyses to numerically quantify the amplification or instability effects of zones whose geometry is indicated on the Level 1 *Map of Seismically Homogeneous Microzones*. However, based on the analyses at this level, the geometries of the above zones may be slightly modified. The Map will be developed based on the amplification values obtained for each zone using the schedules (*FA* and *FV*; Chapter 2.5) and the numerical values assigned to the instability-prone zones according to the simplified methods described in Chapters 2.6 and 2.7.

2.4.2 LEGEND AND MAP FIELD

The map field and the related explanatory legend (Figure 2.4-1) show three types of zones. Two of these types overlap each other.

The types of zones are:

a. Stable zones, in which no effect of any nature is assumed, except for ground motion, which depends on energy and distance from the event.
The zones of this category will be blue colour-coded.
General data about the stable zones will be reported.
It is worth recalling that the zones defined as stable in the Level 1 *Map of Seismically Homogeneous Microzones*, though with a value of $Jv > 10$-15 or $V_s < 800$ m/s might not be classified as stable.

b. Stable zones prone to amplification, where ground motion amplification is expected as an effect of local lithostratigraphic and morphological conditions.
The zones of this category will have the numerical values of *FA* and *FV* inferred form the schedules.
This zone will be colour coded using yellow-to-red in correspondence with increasingly higher *FA* values.
The legend will provide general information about the amplification-prone stable zones.

c. Instability-prone zones, where the expected and dominant seismic effects may be ascribed to permanent ground deformations. Graphically, the zone will be green colour-coded.
The zones identify four categories of deformation effects:

- Slope instability. These zones will have the *FRT* code, if the instability involves soils and *FRR* if the instability involves rock. Each zone will be identified with a number from 1 to n. The legend will be a table with the zone identifier (e.g. FRT_3 or FRR_4) and the quantitative parameter produced by simplified numerical analysis (maximum displacement in cm for soils and maximum distance of arrival of blocks in m for rocks).
- Liquefaction. These zones will have the *LI* code and a sequential number from 1 to n. The legend will be a table with the zone identifier (e.g. LI_3) and the quantitative parameter produced by simplified numerical analyses (liquefaction potential)*.

* Specific Guidelines are being developed.

- Differential settlement. These zones will have the *CD* code and a sequential number from 1 to n. No quantitative parameters will be specified at this level*.
- Active and capable faults. These zones will have the *FA* code and a sequential number from 1 to n. No quantitative parameters will be specified at this level**.

In case of overlapping of **instability-prone zones and local amplification-prone stable zones**, the background colour (from yellow to red) will show the stable zone prone to local amplification, whereas the zone prone to instability will be shaded using overlaid green lines (oblique from left to right and from bottom to top) and show its code and sequential number.

* Specific Guidelines have been developed in 2015. Italian edition: http://......

** Specific Standard have been developed from 2011. www.protezionecivile.gov.it.

2.5 Procedures for Creating and Using Amplification Schedules (Level 2)

2.5.1 PURPOSE

Defining procedures for creating and using schedules (for lithostratigraphic and topographic amplification), based on quantitative input data that may be simply and economically acquired. The schedules will provide parameters for the characterisation of local seismic response at the surface in the following cases.

2.5.2 LIMITS ON THE UTILISATION OF SCHEDULES

2.5.2.1 LIMITS ON THE UTILISATION OF SCHEDULES FOR LITHOSTRATIGRAPHIC AMPLIFICATION

The following procedure assumes a quantitative approach to the estimation of local seismic response in terms of amplification factors. The procedure applies to changes in ground motion induced by specific local lithostratigraphic characteristics and does not consider topographic effects, 2D effects and possible increases in ground motion caused by permanent deformations.
The use of schedules is recommended for a geological and geotechnical condition that may be equated to a 1D physical model, i.e. to *n* homogeneous, continuous, parallel, horizontal, flat layers of infinite extent and viscoelastic behaviour. Each layer has a thickness *h*, a density ρ, an initial shear modulus G_0 and damping ratio (D) decay curves. These layers rest on the seismic bedrock.
The choice of whether or not to use schedules will be facilitated by the elements shown in the Level 1 *Map of Seismically Homogeneous Microzones* and, namely, by the map elements referring to:

- steep features at the surface (for identifying possible amplification effects due to topography);
- complex features of the buried geological bedrock (for identifying possible 2D amplification effects);
- lithostratigraphic sequences having stiff soils resting on soft soils (profile of V_s with velocity inversions);
- instability-prone areas, if any (possible increases in amplification).

These factors may help identify the need to resort to more complex models than those used for creating the schedules, by adopting appropriate computation methods.
If buried basins (concave features of the seismic bedrock with fills of soft soils) are present, then 2D effects may play a dominant role and make the estimations with the schedules unrealistic. To initially and approximately assess the presence of this type of effect and thus the applicability of the schedules, reliance may be made on the simplified approach proposed by Bard & Bouchon (1985) and on data regarding buried morphology and expected seismic impedance contrast at the base of the sediments. As suggested in the above publication, the assessment may be carried out using the following formula:

$$\frac{h}{l} \leq 0.65/\sqrt{C_v - 1}$$

where:

h is the depth of the valley (maximum thickness of the deposit)

l its semi-amplitude

C_v the ratio of the velocity V_s in the seismic bedrock to the average velocity in the soils filling the valley.

If the above expression is satisfied and if the damping of surface waves is high, then the amplification at the centre of the valley may be estimated using 1D models. When moving far from the centre of the valley and closer to its sides, the approximation offered by the 1D method becomes less reliable. If the above expression is not satisfied, use must be made of a 2D analysis (in practice moving to a higher level of study - Level 3).

A velocity inversion in the V_s profile of a lithostratigraphic sequence is considered to occur when a stiff soil overlaps a softer soil with a $V_{s\ stiff}/V_{s\ soft}$ ratio of > 2 and the V_s of the stiffer layer exceeds 500 m/s. These cases require a higher level of study.

However, the use of the schedules is allowed if the inversion is due to a stiffer layer with a thickness of less than $V_s/60$, where V_s is the average velocity of the entire cover of the seismic bedrock expressed in m/s.

The use of schedules for calculating local amplification in areas with permanent deformations is not recommended and a higher level of study will be needed (Level 3).

2.5.2.2 LIMITS ON THE UTILISATION OF SCHEDULES FOR TOPOGRAPHIC AMPLIFICATION

For particularly high cliffs and long ridges, Eurocode 8 identifies the angle formed by the slope (α) and the height of the relief (H) as the discriminating elements to define a topographic amplification factor. Based on the above-mentioned European legislation, topography may - to a first approximation - be neglected. Therefore, schedules may be used for lithostratigraphic amplification if $\alpha < 15°$ and $H < 30$ m. In general, the lithological effect prevails over the morphological effect; if the two effects are expected to be combined, preference will be given to the former. The following paragraphs define a methodology that may be applied only to a seismic bedrock with particular topographic characteristics.

2.5.3 GENERAL CRITERIA FOR CREATING SCHEDULES FOR LITHOSTRATIGRAPHIC AND TOPOGRAPHIC EFFECTS (TO BE DEFINED BY THE REGION)

2.5.3.1 LITHOSTRATIGRAPHIC EFFECTS

2.5.3.1.1 Input Data and Model Building

For the schedules, the Region should define:

- Seismic inputs

  These inputs may be both synthetic and real accelerograms, response spectra or power density spectra. A minimum of four (4) accelerograms are recommended for each model (NEHRP, 2003). The number of accelerograms will depend on the variation of the hazard level in each Regional territory (seismic macro-zones).

Synthetic accelerograms shall be defined in accordance with regional seismic hazard studies. Particular reference should be made to ground motion with a probability of exceedance of 10% in 50 years (T_{nt} = 475). For particular types of buildings or structures and/or verifications, different return periods may be used (e.g. 72, 975, 2475 years). A regional hazard disaggregation study is recommended to determine the most significant magnitude-distance pairs vs. the investigated return period (chapter 2.8).

When using real accelerograms, they must be selected in light of regional seismotectonic characteristics and, namely, the type of source (compressional, extensional, strike-slip movements) and the magnitudes and distances of events mostly likely to contribute to regional hazards.

Selected events must always be those related to rock or very stiff terrains.

When using real accelerograms it is recommended to limit alterations designed to ensure that individual recordings respect an assigned spectral shape and to produce the compatibility with the input spectrum as the average of the set of accelerograms. A change obtained by scaling all the points of the real accelerogram by 20% at the most is acceptable. For conservative purposes, the real accelerograms so selected may be integrated with synthetic accelerograms, with assigned spectral shapes and PGAs.

As synthetic and real accelerograms are defined at the surface, it may be necessary - depending on the software used - to transfer the motion at the surface to the interface between the seismic bedrock and the soil covers, thus calculating a deconvolution to transfer the signal to the desired depth.

Reference lithological models, i.e. the prevailing lithology of earth cover and seismic bedrock.

- A set of lithological models will be defined; some models will be general; other models will be specific for important and representative local (regional) settings. While the depth of the seismic bedrock may vary, it must reach at least 50 m.
- Stiffness decay curves and damping increase curves.
  These curves will be associated with the prevailing cover rock sequences. Generally, the stiffness decay curves and the damping factor increase curves are selected on the basis of relations found in published literature (Seed *et al.*, 1986; Vucetic & Dobry, 1991; Rollins *et al.*, 1998; Naso et al. 2005; Regione Lombardia, 2006). Specific laboratory tests are recommended when the published curves are deemed inadequate for the soil types considered in the numerical simulations.
- Profiles of V_s corresponding to different average values of V_s.
  These profiles will be associated with the reference lithological models. The average V_s of these profiles will cover a velocity range of 100 to 750 m/s with increments of 50 or 100 m/s.
  The V_s profiles will usually be 3: 1 at constant velocity (average Vs) for all the thickness of the earth covers, 2 at constant but different gradients (however, both profiles will have the same average V_s).

2.5.3.1.2 Numerical Simulations

Numerical simulations may be carried out by using 1D equivalent linear or non-linear software models. If the local seismic response is strongly non-linear (e.g. high levels of acceleration and very soft soils), the use of non-linear software models is preferable.

These simulations will take into account the uncertainties associated with the choice of factors contributing to estimating the local seismic response (seismic input, thickness of soil covers, decay curves, V_s profile). For this purpose, various simulations combining the different possible choices will be run, producing amplification factors with a probability of exceedance of 50% (median values).

2.5.3.2 TOPOGRAPHIC EFFECTS

2.5.3.2.1 Input Data and Model Building

Topographic profiles of different shapes and geometries.

2.5.3.2.2 Numerical Simulations

Numerical simulations may be carried out by using at least 2D linear elastic software models. These simulations will take into account the uncertainties associated with the choice of factors contributing to estimating the local seismic response (seismic input, different geometries). For this purpose, various simulations combining the different possible choices will be run, producing amplification factors with a probability of exceedance of 50% (median values).

2.5.3.3 DETERMINATION OF THE *FA* AND *FV* FACTORS FOR LITHOSTRATIGRAPHIC EFFECTS

2.5.3.3.1 Results of the Schedules

The results of the schedules will consist of 2 amplification factors:

- *FA* at low period (determined around the natural period at which the maximum acceleration response is recorded);
- *FV* at natural period (at which the maximum pseudo-velocity response takes place).

The *FA* and *FV* factors will be calculated from the results of amplification analyses as per the procedure described in the following paragraphs.

Depending on the input description, 2 cases will be distinguished:

- input spectrum with uniform probability, supplied by the Region;
- (synthetic and real) input accelerograms.

2.5.3.3.2 Determination of the FA and FV Factors with Uniform-Probability Spectrum Input

a. Determine the maximum period of the input spectrum (TA_i) and of the output spectrum (TA_o);

b. Calculate the average values of the input spectra ($SA_{m,i}$) and of the output spectra ($SA_{m,o}$) around TA_i and TA_o

$$SA_m = \frac{1}{TA} \int_{0.5*TA}^{1.5*TA} SA(T)\,dT$$

where:

SA_m is the average value of the spectrum, which may be $SA_{m,i}$ or $SA_{m,o}$;

$SA(T)$ is the elastic acceleration response spectrum equal to SA_i for the input, SA_o for the output;

TA is equal to TA_i for the input and to TA_o for the output.

c. Calculate the periods (TV_i and TV_o) of maximum value of the pseudo-velocity spectra so defined:

$$SV(T) = SA(T) * \frac{T}{2\pi}$$

where:

$SV(T)$ corresponds to $SV_i(T)$ for the input and $SV_o(T)$ for the output, respectively.

d. Calculate the average values of the spectra (SV_m,i and $SV_{m,o}$) around TV_i and TV_o:

$$SV_m = \frac{1}{0.4 * TV} \int_{0.8*TV}^{1.2*TV} SV(T)dT$$

where:

SV_m is the average value of the spectrum, which may be $SV_{m,i}$ or $SV_{m,o}$;

TV may be TV_i and TV_o for the input and output, respectively.

The integration interval is shorter than the acceleration interval because the velocity spectrum generally presents a more regular pattern.

e. The FA value is equal to the ratio $SA_{m,o}$ / $SA_{m,i}$.

f. The FV value is equal to the ratio $SV_{m,o}$ / $SV_{m,i}$.

2.5.3.3.3 Determination of the FA and FV Factors Using (Synthetic and Real) Accelerogram Input

a. Determine the elastic response spectra of the input and output accelerograms.

b. Referring to the previous case, regularising[41] each spectrum to identify a single maximum value (and thus the corresponding period TA) for each..

Follow the procedure described in paragraph 2.5.3.3.2 for the uniform-probability input spectra starting from step b, and acting on the regularised spectra.

2.5.4 GENERAL CRITERIA FOR USING THE SCHEDULES (TO BE DEFINED BY THE SM IMPLEMENTING PARTY)

2.5.4.1 INPUT DATA AND UTILISATION OF THE SCHEDULES FOR LITHOSTRATIGRAPHIC EFFECTS

The party implementing the local seismic response study is responsible for collecting the input data used to select the schedules. This data will include:

41 As accelerogram response spectra are generally irregular, reference is usually made to spectra where the natural period at which the maximum ordinates are obtained is more clearly identifiable.

- the seismic hazard macro-zone to which the site belongs; each macro-zone will correspond to a different seismic input;
- the dominant lithology of the soil covers which may be inferred from Level 1 results;
- the depth of the seismic bedrock, i.e. the depth where S waves reach a velocity of more than 800 m/s;
- the pattern of the shear wave velocity vs. depth and the average velocity VsH of S waves in the soil covers down to the seismic bedrock; the latter will be given by

$$V_{sH} \cong \frac{H}{\sum_{i=1}^{n} \frac{h_i}{V_{si}}}$$

where:
H is the total thickness (in m) of the soil covers down to the seismic bedrock;
h_i is the thickness (in m) of the *i-th* layer of the n layers making up the soil cover;
V_{si} is the velocity (in m/s) of the *i-th* layer.

In principle these data may be inferred from an experimentally estimated shear wave velocity profile. Where the experimental velocity profile does not permit to determine the position of the seismic bedrock (e.g. the measured velocities do not exceed 800 m/s), reference will be made to indirect indications. These indications may be obtained by combining Level 1 results (depth of the geological bedrock) with the measurement of the natural period T_0 of the site of the sedimentary cover (identification of the depth of the most important impedance contrast). This produces:

$$T_0 = \frac{4h_a}{V_a}$$

where:
h_a is the depth of the geological bedrock[42];
V_s is the average velocity of S waves as far as the latter interface; therefore, it may be assumed to have the value of V_{sH} , obviously with less reliability than with direct measures.

Conversely, ha may be inferred from a general estimation of V_a.
The use of V_a and ha in place of V_{sH} and H, respectively, may be considered if both of the following conditions are satisfied; these conditions may be roughly assessed on the basis of the lithostratigraphic and geotechnical characteristics of the deposits and bedrock:

- the velocity contrast in h_a is significant (indicatively greater than 2);
- the soil below h_a is fairly stiff (indicatively, the velocity V_s below h_a is at least equal to 600 m/s; if this velocity exists in a range of 500 to 600 m/s, schedules may be used, however the result should be increased by 10%).

42 It should be noted that measurements taken from the surface may identify a reflection horizon, which is not the seismic bedrock but an impedance contrast.

In brief, the user will access the tables of the schedules for lithostratigraphic amplification using the data described above, in other words with an understanding of:

- the seismic hazard macro-zone;
- the dominant rock sequence;
- the thickness of the soil covers H;
- the average V_{sH} of the soil covers.

2.5.4.2 INPUT DATA AND UTILISATION OF SCHEDULES FOR TOPOGRAPHIC EFFECTS

With regards to merely topographic effects (crests and scarps in the presence of a geophysical bedrock) and where $H \geq 10$ m and $\alpha > 10°$, the input data and for the use of the schedules by the SM implementing party are:

a. for crests (a crest exists only when h is greater than or equal to one-third of H; Figure 2.5-1):

- width at the base of the ridge L;
- width at the crest of the ridge l;
- maximum difference in elevation H and minimum difference in elevation h of slopes.

b. for scarps (a scarp exists only when β is less than or equal to one-fifth of α and h is less than one-third of H; Figure 2.5-2):

- maximum difference in elevation H and minimum difference in elevation h;
- inclination (α) of the main face;
- inclination (β) of the upper face.

2.5.4.3 RECONSTRUCTION OF THE SURFACE ELASTIC SPECTRUM FOR LITHOSTRATIGRAPHIC AMPLIFICATION

The schedules provide 2 amplification factors, *FA* and *FV* (as described in paragraph 2.5.3). Using these amplification factors, the surface elastic spectrum will be reconstructed from:

- uniform-probability input spectrum, provided by the Region;
- the spectrum referred to in the applicable legislation;
- the spectrum representing a set of accelerograms.

The procedure identifies a surface spectrum with a standard shape, consisting of a branch with increasing linear acceleration, a branch with constant acceleration and a branch where acceleration decreases at $1/T$ and thus at constant pseudo-velocity.

The procedure to be followed in each of the above cases is described in the following paragraphs.

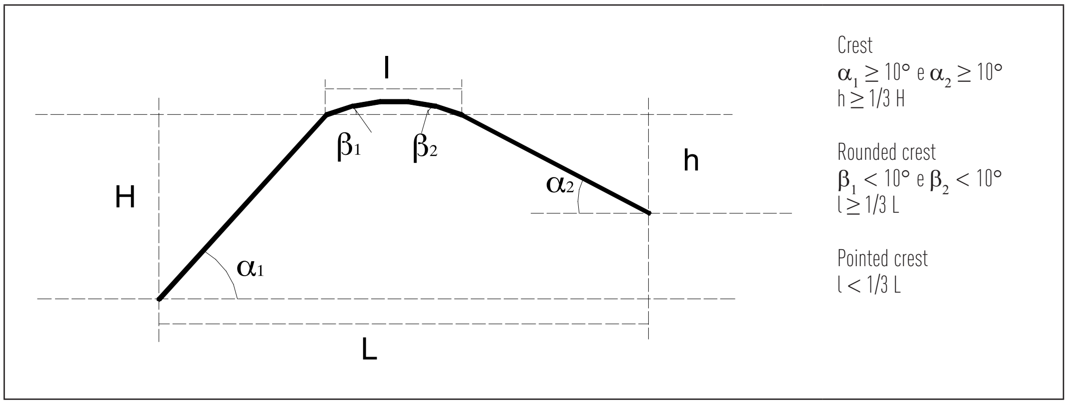


Figure 2.5-1 – Reference diagram for the crest and identification criteria.

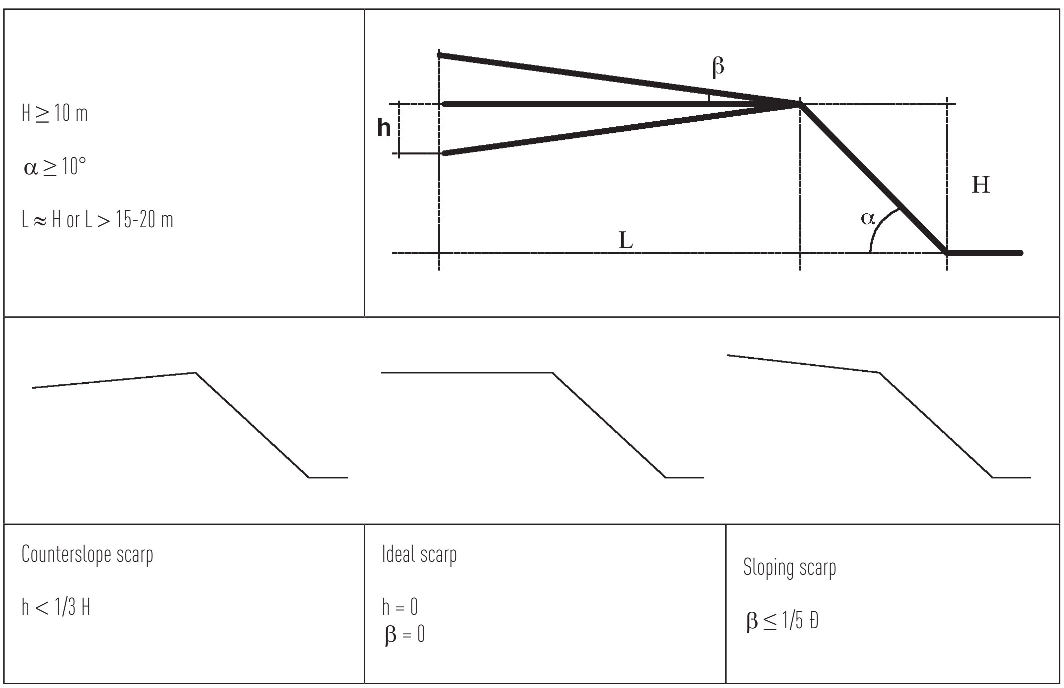


Figure 2.5-2 – Reference diagram for the scarp and identification criteria.

2.5.4.3.1 Uniform-Probability Input Spectrum

The steps of the procedure are as follows:

a. Determine the natural period at which the input spectrum (TA_i) is maximum; as this input is defined on rock, this value will usually range from 0.1 to 0.3 s;

b. Calculate the average spectrum value ($SA_{m,i}$) around TA_i:

$$SA_{m,i} = \frac{1}{TA_i} \int_{0.5*TA_i}^{1.5*TA_i} SA_i(T)dT$$

where:

SA_i is the input spectrum (elastic acceleration response spectrum);

c. Determine the input pseudo-velocity spectrum (SV_i) from the acceleration spectrum and the natural period (TV_i) at which the pseudo-velocity spectrum reaches maximum value.

$$SV_i(T) = SA_i(T) * \frac{T}{2\pi}$$

For the input, TV_i generally lies in the range of periods from 0.6 to 1.4 s;

d. Determine the average value of the spectrum ($SV_{m,i}$) at TV_i:

$$SV_{m,i} = \frac{1}{0.4 * TV_i} \int_{0.8*TV_i}^{1.2*TV_i} SV_i(T)dT$$

where:

SV_i is the input spectrum (elastic velocity response spectrum).

The integration interval is shorter than the acceleration interval because this spectrum has a more regular pattern.

In practice, the uniform-probability spectrum is enveloped by a standard spectrum whose constant-acceleration branch is equal to $SA_{m,i}$ and the constant-velocity branch equal to $SV_{m,i}$.

e. Infer the values of *FA* and *FV* from the schedules;

f. Determine the natural period at which the two branches of the surface spectrum (at constant acceleration and constant velocity) meet:

$$T_c = 2\pi \frac{SV_{m,i} FV}{SA_{m,i} FA}$$

g. Determine T_B as 1/3 * T_C ;

h. Assume the initial branch of the spectrum between $T= 0$ and $T = T_B$ to be linear with $SA(0) = SA_i(0) * FA$ and $SA(T_B) = SA_{m,i} * FA$;

i. The branch of the spectrum at constant spectral acceleration between T_B and T_C has ordinates equal to $SA_{m,i} * FA$;

j. The branch of the spectrum at constant velocity ($T > T_C$) has ordinates equal to $SA_{m,i} * FA * T_C/T$;

k. The spectrum obeys the previous expression until $T = T_D$[43].

43 The value of the natural period T_D at which the branch at constant velocity is no longer valid is specified in the applicable legislation and is generally equal to about 2 s.

2.5.4.3.2 Application to the Input Spectrum Referred to in Applicable Legislation (Ground Type A)

The above-mentioned value of $SA_{m,i}$ corresponds to the constant acceleration referred to in applicable legislation. The value of $2\pi*SV_{m,i}$ corresponds with the spectrum defined by the legislation for $T = 1s$; therefore, the previous procedure may be followed from step f onward.

2.5.4.3.3 Synthetic and Real Input Accelerograms

a. Determine the elastic response spectrum of each input accelerogram;

b. Use the average of the spectra mentioned in step a;

c. As the accelerogram response spectra are generally irregular, refer to the previous cases and regularise the spectrum described in step b to identify a single maximum value and thus the corresponding period (T_A).

Follow the procedure for the uniform-probability input spectra starting form step b of paragraph 2.5.4.3.1 and using the regularised spectrum.

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2.6 Procedures for Defining Slope Instabilities (Level 2)

The following procedures are aimed at "quantitatively" estimating the effects of an earthquake in a potentially unstable area, in view of land planning and management. The procedures establish a hierarchy of relative hazards in various zones, useful to land-use studies and local and/or emergency plans. In particular, landslide areas or landslide-prone areas during and/or after the design earthquake must be identified, distinguishing between landslides on soil slopes and rock slides. When sufficient morphological, geological, pluviometric, stratigraphic and geotechnical data are available, the landslide hazard under seismic conditions may be quantified using simplified analyses for comparative study of slope instability at a vast scale.

2.6.1 LANDSLIDES ON SOIL SLOPES

There are primarily two methods of analysis used to verify slope stability under seismic conditions: "pseudo-static" methods and "dynamic" methods.
Pseudo-static methods, deriving from Okabe's original proposal (1924), assume that the seismic action is constant in time and space and consider the same action to be an inertial force proportional to the weight W of the potentially unstable mass through a proportionality coefficient known as the "seismic coefficient". The value of this coefficient is defined by national seismic legislation and depends on the seismicity of the area. Eurocode 8 suggests the following values for the horizontal and vertical components of the seismic coefficient:

$K_h = 0.5a$ $\qquad\qquad$ $K_v = 0.5\,K_h$

where:
$a = a_{max} / g$ is the ratio of the maximum design acceleration to the gravity acceleration g.

The Ministerial Decree issued by the Italian Government on 14 January 2008 provides more diversified values.
The decree assumes that failure occurs when the safety coefficient against sliding F_d, defined as the ratio of the available friction to the mobilised friction, is equal to or lower than 1. Conventionally, stability is considered to exist if F_d is greater than 1.15. This verification criterion may appear particularly conservative. Indeed, given the rapid variability of seismic stresses over time, the safety coefficient may be lower than the predetermined threshold level only during short time intervals.
In particular, as priorities for action are to be set, e.g. for emergency planning, this type of assessment cannot be based only on the pseudo-static safety factor (indistinctly lower than 1 for all potentially unstable zones).
To assess slope stability under seismic stresses it is generally preferable to use the second criterion of analysis. In this case, however, the data required to obtain reliable results might not be part of a Level 2 SM analysis.
The methods of dynamic analysis based on mathematical models and laboratory testing involve, first

of all, a comparison between the tensional state induced by the soil and the resistance of the material (under dynamic conditions). Provided that the resulting resistance is not significantly reduced, these methods allow for the determination of the permanent downslope displacement under the action of a design earthquake, realistically described in its amplitude and duration characteristics (Newmark, 1965). The permanent displacements induced by seismic motion are calculated in three successive steps:

1. Through a conventional stability analysis with a safety factor equal to 1, assessing the maximum external acceleration at which the slope is under limit equilibrium or incipient failure conditions. This value of external acceleration is conventionally defined as "threshold *ac*celeration" a_c; this acceleration, normalised with respect to the acceleration of gravity is referred to as the "critical seismic coefficient" K_c. If pore pressure variations are disregarded, this coefficient depends exclusively on the geometry of the slope and the mechanical properties of the soils involved. The original method assumes that the coefficient is constant in time and space. Nevertheless, assuming K_c to be constant in time is tantamount to neglecting dynamic effects of strain softening and pore pressure increase, as well as viscous effects in cohesive soils. In contrast, assuming K_c to be constant in space means considering a uniform acceleration field and thus neglecting the effects of seismic response amplification. For K_c, it would be more correct to use the following expression:

$$K_c(t) = K_c(0) * R(t) * D(t)$$

where $K_c(0)$ is the initial critical seismic coefficient; $R(t)$ is a coefficient accounting for strength variation with seismic load application velocity; $D(t)$ is the coefficient of cyclical degradation (Crespellani, 1995).

2. Calculate the temporal distribution of the accelerations induced in the bedrock by the investigated seismic event (reference accelerogram).

3. Finally, determine the displacements along the rupture surface using a double numerical integration of the accelerogram representing the temporal pattern of the inertial accelerations induced in the slope by the earthquake; the integration should be limited to the time intervals in which the velocity of the portion of soil bounded by the rupture surface differs from that of the remainder of the slope.

In view of i) the difficulty of accurately defining the quantities involved at the desired level of study and ii) the intent of establishing a hazard hierarchy among the different potential landslide zones alternative methods may be used. These methods, many of which have been published, are more conservative but more readily usable to predict quantities indirectly related to induced permanent displacements.

According to these simplified dynamic approaches, a simplified assessment is conducted using Newmark's method based on slope angle, an estimated range of mechanical properties and groundwater level. Correlations can then be established for limited areas (as proposed by various authors, including Ambraseys & Menu, 1988) between: i) the quantity D, expressed in units of length and representing the upper range of the results; this quantity can be defined as a displacement indicator; and ii) the critical acceleration ratio K_c/k_m, where $K_c = a_c/g$ (g = gravity acceleration, a_c = critical acceleration) and $k_m = a_{max}/g$.

One of these correlations was developed at a regional scale by Simonelli & Fortunato (1996) for the Italian region of Irpinia. For an indefinite slope consisting of incoherent soils and under different groundwater conditions, these authors determined the relationship between induced permanent displacement and the ratio K_c / k_m. This calculation relies on accelerograms deriving from the signals recorded by the ex-ENEL network during the earthquake of 23 November 1980. Other authors have focused their attention on the expression of the critical seismic coefficient upon variations in the assumed failure mechanism, and of the presence of slope reinforcements, subsequently studying the correlation with induced permanent displacements.

Another study worthy of mention is that conducted by Cavalera & Brancucci (1995). The following paragraphs report various formulas from this study concerning the critical seismic coefficient and its correlation (on the assumption of an indefinite slope) with induced permanent deformation D for 8 artificial, spectrum-compatible accelerograms on stiff soil (as per Annex 2 of OPCM 3274/2003), considering a Type A foundation soil in seismic zone 2.

In particular, the following relations were obtained:

- for plane sliding surfaces (indefinite slope)

$$K_c = \frac{A_1 + A_2 - A_3 + A_4}{A_5} \tag{2.6-1}$$

where:

$A_1 = c'/\cos\alpha$

$A_2 = \gamma\, z\, (\cos\alpha \tan\phi' - \mathrm{sen}\alpha)$

$A_3 = \gamma_w\, z_w \cos\alpha \tan\phi'$

$A_4 = T_{amm.} (\cos\alpha + \mathrm{sen}\alpha \tan\phi')$

$A_5 = \gamma\, z\, (\cos\alpha + \mathrm{sen}\alpha \tan\phi')$

with:

c' = soil cohesion

α = ground level inclination

γ = weight of unit of volume of soil

z = height of the belt

ϕ' = internal soil friction angle

γ_w = weight of unit of volume of water

z_w = groundwater elevation from the potential sliding surface

$T_{amm.}$ = admissible tensile strength of the reinforcement present in a band of uniform width.

- wedge failure

$$K_c = \frac{B_1 + B_2 - B_3 + B_4}{B_5} \tag{2.6-2}$$

where:

$B_1 = c' H / \mathrm{sen}\theta$

$B_2 = W(\cos\theta \tan\phi' - \mathrm{sen}\theta)$

$B_3 = U\,\mathrm{sen}\theta$

$B_4 = S_{amm.}(\cos\theta + \mathrm{sen}\theta \tan\phi')$

$B_5 = W(\cos\theta + \mathrm{sen}\theta \tan\phi')$.

with:

H = height of the failure wedge

θ = inclination of the failure surface

W = own weight of the failure wedge

U = pressure exerted by groundwater on the failure surface

$S_{amm.}$ = total admissible tensile resistance exerted by all slope reinforcements

- for circular sliding surface

$$K_c = \frac{\sum_{i=1}^{n}(C_1 / C_2) + \sum_{i=1}^{m} C_3 - \sum_{i=1}^{n} C_4}{\sum_{i=1}^{n} C_5} \tag{2.6-3}$$

where:

$C_1 = [c' \Delta x_i + (w_i - u_i \cos\theta_i)\tan\phi']\, r$

$C_2 = \cos\theta_i (1 + \tan\phi' \tan\theta_i)$

$C_3 = T_{amm.i}\, y_i$

$C_4 = w_{ij}\, r\, \mathrm{sen}\theta_i$

$C_5 = w_i\, y_{Gi}$

with:

n = number of bands into which the slope has been divided

Δx_i = width of the i-th band

w_i = weight of the i-th band

u_i = neutral pressure acting on the base of the i-th band

θ_i = average inclination of the base of the i-th band with respect to the horizontal

r = radius of the critical circle; m = number of reinforcements planned in the slope

$T_{amm.i}$ = admissible tensile strength of the i-th reinforcement

y_i = distance of the i-the reinforcement from the centre of the critical circle

y_{Gi} = distance of the centre of mass of the i-th band from the centre of the critical circle

Figure 2.6-1 illustrates the results obtained for an indefinite slope.

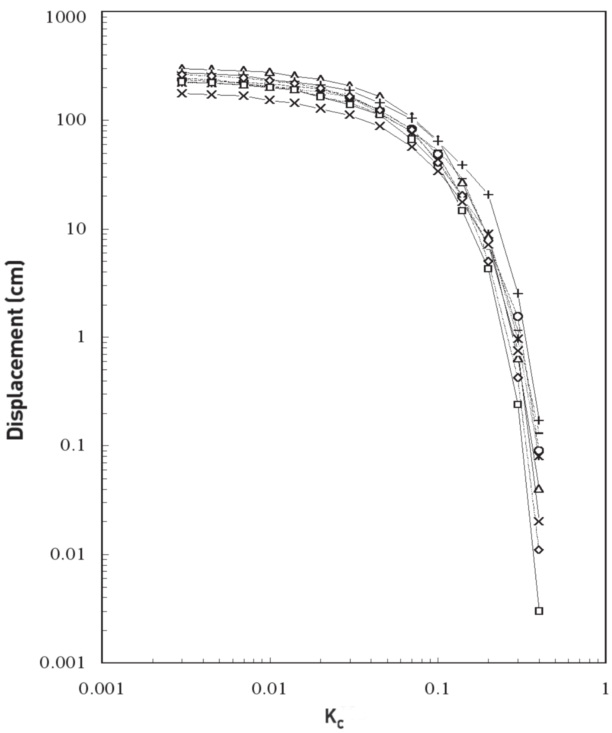

Figure 2.6-1 – Induced permanent displacement – critical seismic coefficient for 8 artificial, spectrum-compatible accelerograms on stiff soil A, seismic zone 2, for an indefinite slope (Cavalera & Brancucci, 1995)

Finally, it is worth recalling that simplified empirical correlations are available to calculate induced permanent displacement (always understood as a hazard indicator and not as an actual physical entity), provided that the epicentral magnitude, the epicentral distance and the critical seismic coefficient k_c are known (Romeo, 2000).

The expression proposed by Romeo is:

$$\log_{10} D = -1.281 + 0.648M - 0.934\log_{10}\sqrt{RE^2 + 3.5^2} - 3.699K + 0.225S \pm 0.418 \quad (2.6\text{-}4)$$

where:

M = epicentral magnitude of the earthquake

RE = epicentral distance (km)

$K = k_c g / a_{max}$

S = amplification coefficient due to outcropping rock sequences; it ranges from 0 (rock or stiff soil) to 1 (soft soil with V_s< 400 m/s and thickness < 20 m).

The value K can be calculated using detailed formulas similar to those previously described (2.6-1, 2.6-2, 2.6-3) or other simplified expressions (Jibson, 1993) similar to:

$$a_c = (FS - 1)g \cdot \sin\psi_p \quad (2.6\text{-}5)$$

where:

FS is the safety factor of the slope under static conditions

g is the gravity acceleration

ψ_p is the angle of inclination of the sliding surface on the assumption of a horizontal translation.

2.6.1.1 THE UTILISATION OF RESULTS FROM SIMPLIFIED DYNAMIC METHODS

It is worth stressing, once again, that the value of the schedules, tables and graphs obtained with these methods is only comparative and cannot be exported to the scale of a building or structure, as this would comport risks in terms of safety and costs.

The values obtained from the expected maximum displacements of a potentially unstable slope should only be considered as indicators of the level of damage that the study area may suffer as a consequence of a seismic event of a given extent and not as real displacements. Hence, for design purposes, more in-depth investigations are needed for:

- definition of kinematic rupture;
- procedure for calculating earthquake-induced stresses along a slope, taking into account the non-linearity of the constitutive link and possible geometric discretisations which may be adopted;
- choice of the constitutive model of the soil;
- prediction of the effects related to pore pressure changes;
- prediction of the onset of progressive rupture phenomena, if any.

The topic is complex and difficult to represent in schedules or tables, except for comparative estimations. Therefore, even these more evolved methods may have considerable limitations in terms of reliability.

2.6.2 ROCK SLIDES

For seismic landslides involving fractured rock masses, estimations will be made to delimit the landslide deposit area, which is in turn connected with the maximum distance covered by the rock blocks/dihedrals susceptible to collapse. This areal demarcation will derive from empirical relations based on:

- classification of the rock mass based on seismic rock-fall susceptibility;
- parameters such as the minimum shadow angle or equivalent friction angle;
- predominantly geomorphological observations of forms and deposits related to prior collapse phenomena.

2.6.2.1 CLASSIFICATION OF ROCK MASS BASED ON SEISMIC ROCK-FALL SUSCEPTIBILITY

With regard to the definition of seismic rock-fall susceptibility, reference should be made to the approach introduced by Harp & Noble (1993) for areas experiencing rock falls induced by an earthquake of $M = 6.0$. Based on the quality of the rock mass (Q), determined in-situ using a modified version of Barton's classification (1998), and thanks to the introduction of an exponential relation of the form $M = Ne^{-aQ}$, the expected number of rock falls may be indicatively determined.

$$\ln M = 1.81 - 0.49\,Q$$

where:

M = average number of rock falls per site;

Q = quality index of the rock mass according to Barton.

The relative probability of rock falls for a magnitude 6 earthquake may be predicted for different types of rock slopes with assigned ranges of Q. By applying the proposed relation to real cases, the studied rock outcrops may be discretised into classes of increasing susceptibility according to their Q value (class A, $Q = 0.1$ - 1.41, highly susceptible; class B, $Q = 1.42 - 2.83$, susceptible; class C, $Q = 2.84 - 3.87$, moderately stable; and class D, $Q > 3.87$). Based on the above classes, zones with homogeneous values of the modified Q value (see Barton, 1998) are consequently plotted along the investigated slope.

2.6.2.2 PARAMETERS SUCH AS THE MINIMUM SHADOW ANGLE OR THE EQUIVALENT FRICTION ANGLE

The semi-quantitative assessment of the expected trajectories of rock blocks that are susceptible to collapse is based on the estimation of their potential maximum advance, so as to divide the investigated area into zones with different levels of hazard (Varnes, 1984). This approach relies on the concept of the so-called shadow cone, i.e. the identification of the maximum point of arrival, using zenith angle limit values (e.g. 28°). This point is defined as the angle - with respect to the horizontal - of the line joining the point of maximum advance with the apex of the debris cone (minimum shadow angle).

2.6.2.3 PREDOMINANTLY GEOMORPHOLOGICAL OBSERVATIONS OF FORMS AND DEPOSITS RELATED TO PRIOR COLLAPSE PHENOMENA

The results obtained from the analyses mentioned in the first two points of paragraph 2.6.2 will be validated. These results will be compared with geological-technical and geomorphological records of slope debris, which may also indicate the state of activity of eventual landslides.

Another method (Onofri & Candian, 1979) consists of using the equivalent friction angle or slope inclination angle (ϕ_p). This angle is calculated by starting from the highest point of the detachment zone and joining it with the rock mass that has reached the maximum run-out zone. This process generally yields values of 28.34° to 40.73°. Statistical processing of the data indicated a Gaussian distribution of the cumulated percentage frequencies ϕ_p, identifying the lower range as $\phi_p = 27.15°$ at a confidence interval of $P = 0.99$.

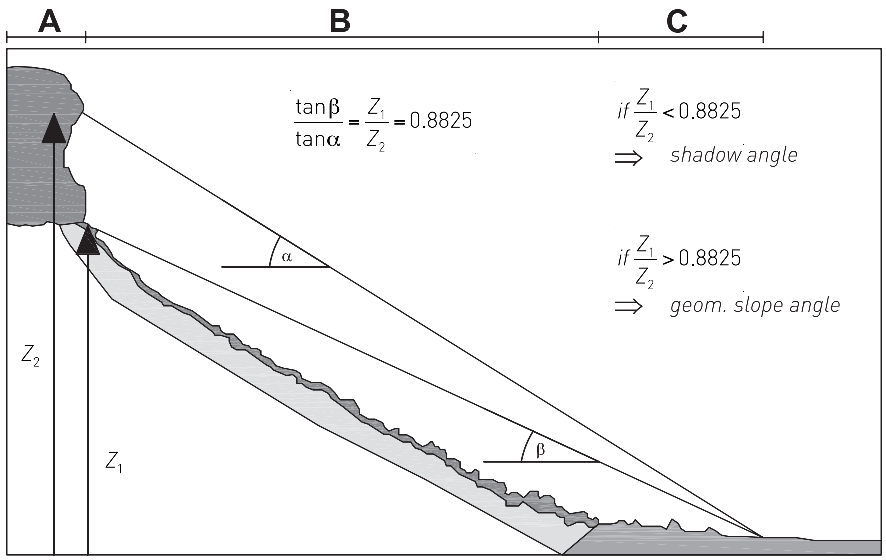

Figure 2.6-2 – Soil parameters for applying the method proposed by Onofri & Candian (1979)

The choice between the two methods may be theoretically decided, using the relation shown in Figure 2.6-2, which may be summarised as follows:

- if the ratio $Z_1/Z_2 < 0.8825$, then the minimum shadow angle is used;
- if this ratio is greater than 0.8825, then the slope inclination angle is used.

For massive collapses (volumes between 1,000 and hundreds of thousands of cubic metres), some empirical methods are available. These methods permit the calculation of the maximum run-out which may be reached by a landslide based on an initial estimate of potentially unstable volumes. Use should be made of the empirical method most suitable to the assumed volumes and lithological characteristics of the site. The width and shape of the landslide deposit will be demarcated taking into account the morphology of the slope and the area of possible run-out. These methods are valid above all for high volumes.

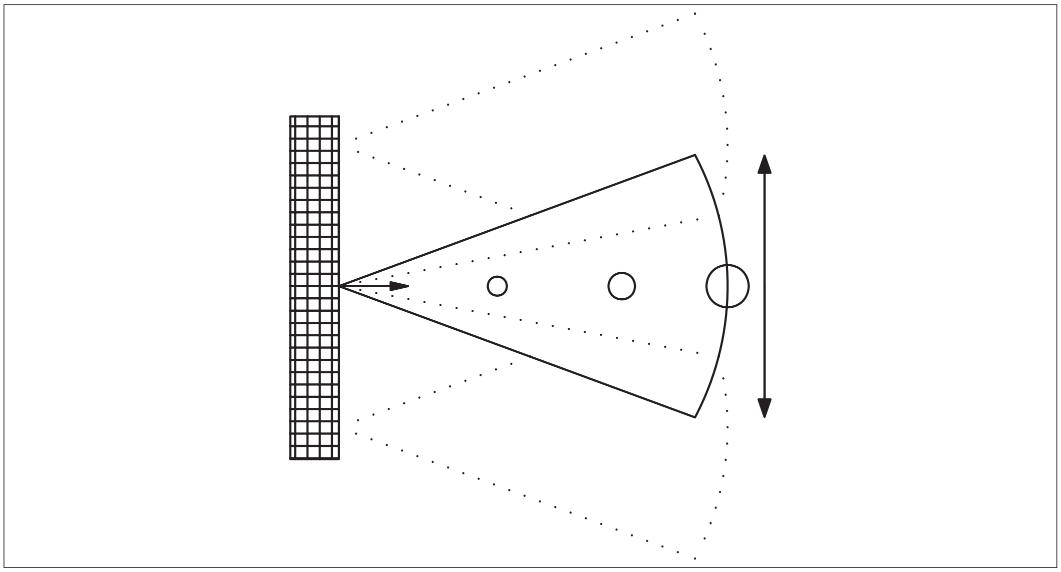

Figure 2.6-3 – Plan view of a shadow cone containing the most likely run-out trajectory

The methodology reported below is merely indicative and requires more detailed investigations specific to each case. Scheidegger (1973) provides the formula:

$\log f = a*\log V + b$

where:

f = H/h

x = maximum distance which may be reached by the landslide (m)

H = difference in elevation (m)

V = assumed volume of the involved mass

a = -0.15666

b = 0.62419

Conversely, Davies (1982) proposes a relationship between the volume (V) and distance reached (R_a):

$R_a = 9.98*V*0.33$

Tianchi (1983) correlates the volume (V) of the landslide with the distance reached (L):

$\log (H/L) = A + B \log V$

where:

H = difference in elevation (m)

A = 0.6640

B = -0.1529

The Appendices report a detailed technical data sheet (technical data sheet 3.1.2)*.

* Not included in the english edition.

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2.7 Procedure for Assessing the Likelihood of Liquefaction (Level 2)

2.7.1 ASSESSING THE LIKELIHOOD OF LIQUEFACTION PHENOMENA

The liquefaction hazard will be verified based on the possibility of concurrent triggering factors (characteristics of expected earthquakes) and factors of predisposition (soil susceptibility).

Soil susceptibility will be assessed through in-situ testing (SPT and/or CPT and/or in-hole geophysical tests, such as DH, CH and/or ECPT), exploring a sufficient number of vertical boreholes, in relation to the importance of the building or structure, the extent of the study area and the need to determine the spatial variability of the stratigraphic and geotechnical characteristics of the deposit. Appropriate analyses will be conducted to determine the extent of fluctuations in groundwater levels, choosing the least conservative conditions.

In the explored verticals, potential liquefaction will be estimated with the "simplified methods" outlined in the following paragraphs. To this end, for each vertical, the peak acceleration $a_{max\,s}$ at the surface of the deposit will be assessed by analysing the local seismic response. This analysis may be omitted if Level 2 SM studies conducted in the area have already provided the values of $a_{max\,s}$ for the site. The analysis of local seismic response will require in-situ tests to measure V_s, dynamic laboratory tests (resonant column and/or cyclical torsional shear tests) to determine the laws of variation of the shear modulus G and the damping ratio D with the shear deformation amplitude γ. When software programs are used to analyse local seismic response in terms of effective stresses, cyclical liquefaction resistance tests must be made of representative samples to the obtain the software input parameters. Samples must be undisturbed and of excellent quality.

The results of the study will be presented by plotting the liquefaction safety factor vs. depth in each of the explored verticals. The liquefaction potential index I_L (see below) must also be determined for each vertical. If:

- $0 < I_L \leq 5$, low liquefaction hazard;
- $5 \leq I_L \leq 15$, high liquefaction hazard;
- $I_L > 15$, extremely high liquefaction hazard.

2.7.1.1 CASES IN WHICH LIQUEFACTION MAY BE EXCLUDED

The probability that liquefaction occurs in saturated sandy soils is considered low or zero when at least one of the following conditions is satisfied[44]:

1. Expected seismic events with a magnitude M lower than 5 (Chapter 2.8);
2. Expected peak acceleration at the surface under free-field conditions of less than 0.1 g;
3. Expected peak acceleration at the surface, under free field conditions, of less than 0.15 g and soils whose characteristics falling under one of the following three categories:

44 See also "Linee guida AGI", 2005.

- fine fraction[45], FC, above 20%, with plasticity index $PI > 10$;
- $FC \geq 35\%$ and strength $(N_1)_{60} > 20$;
- $FC \leq 35\%$ and strength $(N_1)_{60} > 25$

where $(N_1)_{60}$ is the normalised value of penetrometer resistance of the SPT, defined by the relation $(N_1)_{60} = N_{SPT}C_N$ where the coefficient C_N is derived from the expression $C_N = \left(\frac{p_a}{\sigma'_v}\right)^{0.5}$, p_a being the atmospheric pressure and σ'_v the vertical effective stress.

4. Grain size distribution external to the zones shown in Figure 2.7-1 (a) in the case of material with uniformity coefficient $U_C < 3.5$, and in Figure 2.7-1 (b) for uniformity coefficients $U_C > 3.5$.
5. Seasonal average depth of the water table in excess of 15 m below grade[46].

2.7.1.2 METHODS FOR ESTIMATING LIQUEFACTION

Verifications of the likelihood of liquefaction are made using "simplified methods" of geotechnical earthquake engineering. These methods rely on standard geotechnical tests and on the assessment of the safety factor at each elevation z of the deposits included in the first 20 m.

$$F_L = \frac{CRR}{CSR} \bullet MSF$$

where:

$$CRR = \frac{\tau_{ult}}{\sigma'_{v0}}$$

is the normalised resistance (vs. the initial vertical effective stress σ'_{v0}), which may be assessed through schedules (e.g. those of Figure 2.7.2), based on parameters that are inferred from SPT and CPT testing and shear wave velocity V_s measurements[47];

$$CSR = \frac{\tau_{media}}{\sigma'_{v0}} = 0.65 \frac{a_{max\,s}}{g} \frac{\sigma_v}{\sigma'_v} r_d$$ is the stress induced by the earthquake

where:

$a_{max\,s}$ is the peak acceleration at grade of the design earthquake;

g is the gravity acceleration;

σ_v and σ'_v are the vertical total stress and the vertical effective stress at the investigated depth, respectively;

r_d is a seismic action-reducing coefficient that accounts for the deformability of the subsoil; this coefficient may be determined through the simplified relation $r_d = 1-0.015z$;

45 The fine fraction is defined as the fraction passing through the 200 ASTM sieve (0.074 mm).

46 This indicator is valid only if the ground level is horizontal and buildings have shallow foundations. For slopes and/or deep foundations, liquefaction analyses should be extended to greater depth.

47 See "Linee guida AGI", 2005, Appendix E.

The scale factor *MSF* may be determined from Table 2.7-1 based on the expected magnitude of earthquakes[48].

Among the simplified methods, those that are based on CPT tests are particularly recommended. If the factor $F_L > 1.25$, liquefaction is to be excluded, if $F_L < 1.25$, liquefaction is likely. It should be pointed out that, even when $F_L > 1$, permanent ground deformations may occur after the earthquake.

2.7.1.3 DEFINITION AND CALCULATION OF THE LIQUEFACTION POTENTIAL INDEX

The liquefaction potential index IL is given by the following equation:

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

where:

z is the depth from ground level (m)

$w(z) = 10 - 0.5z$ is a function that weighs the contribution of factor F in relation to depth.

At a given elevation z, the factor $F(z) = F$ is worth:

$F = 1 - F_L$ if $F_L \leq 1.0$

$F = 0$ if $F_L > 1.0$

where:

F_L is the liquefaction safety factor at the investigated elevation.

2.7.2 ESTIMATING PERMANENT DEFORMATIONS IN LIQUEFIABLE SATURATED GRANULAR SOILS

The post-seismic permanent deformation ΔH of liquefiable soils ($F_L \leq 1$) may be estimated using the expression:

$\Delta H = \varepsilon_v H$, where H is the height of the liquefiable layer and ε_v (%)the volumetric deformation

$$\varepsilon_v = \frac{\alpha C_r}{1+e_0} \log\left(\frac{1}{1-\dfrac{\Delta u}{\sigma'_0}}\right)$$

where α is an experimental constant that may - to a first approximation - be considered equal to 1;

e_0 is the initial void index;

C_r is the post-cyclical reconsolidation index

$\dfrac{\Delta u}{\sigma'_0}$ is the pore pressure ratio[49].

48 The magnitude (M), and value of bedrock acceleration (a_{max}) both depend on the probability of exceedance during the period of observation (T).

49 For granular soils, the "Linee guida AGI (2005)" propose the following empirical relation to assess the pore pressure increase generated by the seismic stress:

$$\frac{\Delta u_N}{\sigma_0'} = \frac{2}{\pi} \cdot \sin^{-1}\left[\left(\frac{N}{N_L}\right)^{1/2a}\right]$$

To a first approximation:

- the post-cyclical reconsolidation index Cr may be considered equal to $C_r = 0.225\ C_c$ (where C_c is the compression index obtained from oedometer tests);
- the pore pressure ratio $\frac{\Delta u}{\sigma'_0}$ may be evaluated using the chart presented as Figure 2.7-3 or Table 2.7-2, depending on the maximum shear deformation amplitude γ_{max} induced by the earthquake;
- the maximum shear deformation amplitude γ_{max} may be evaluated using the formula

$$\gamma_{max} = 0.65 \frac{a_{max\ s}}{g} \sigma_v r_d \frac{1}{G}$$

where:

$a_{max\ s}$ is the peak acceleration of the design earthquake at ground level; g is the gravity acceleration; σ_v is the vertical total stress; r_d is a seismic action reducing coefficient which accounts for subsoil deformability and which may be determined with the simplified formula r_d = 1-0.015z; G is the shear modulus corresponding to the deformation level γ_{max}, which may be determined either by using the law of variation $G(\gamma)$ obtained form dynamic lab tests or using Table 2.7-3 by applying the reducing factor to the shear modulus G_0.

If $F_L > 1$, then the quantity $\frac{\Delta u}{\sigma'_0}$ may be derived from the relation $\frac{\Delta u}{\sigma'_0} = F_L^{-7}$

The results will be reported in a map identifying the boundaries of the study area, the location of the explored verticals and the cumulative deformation value.

If unsaturated granular soils and/or soft cohesive soils lie above the water table, for each vertical the map must indicate the total deformation value of the unsaturated and/or cohesive layers and the liquefiable layers below the water table.

2.7.3 BIBLIOGRAPHIC REFERENCES

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Seed, H.B. e Idriss, I.M. (1982) - *Ground Motion and Soil Liquefaction During Earthquakes.* Earthquake Engineering Research Institute.

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where Δu_N is the pore pressure increase after N load cycles, σ'_0 is the initial value of the average effective pressure at the investigated depth, N is the number of load cycles at constant amplitude equivalent to the earthquake and N_L is the number of load cycles needed to produce liquefaction in the soil. The experimental constant a may be determined with the following equation as a function of the relative density D_r (in fraction):

$$a = 0.96 \cdot D_r^{0,83} \cdot \varepsilon_\theta$$

The term ε_θ is a lognormal distribution with an average value equal to 1 and a variance equal to 0.12.
It is worth noting that the number of load cycles N may be estimated on the basis of the magnitude of the earthquake from the following table, whereas the number of cycles leading to liquefaction in the soil N_L

M	N
5.0	3.8
5.5	4.0
6.0	4.5
6.5	7.0
7.0	10.0

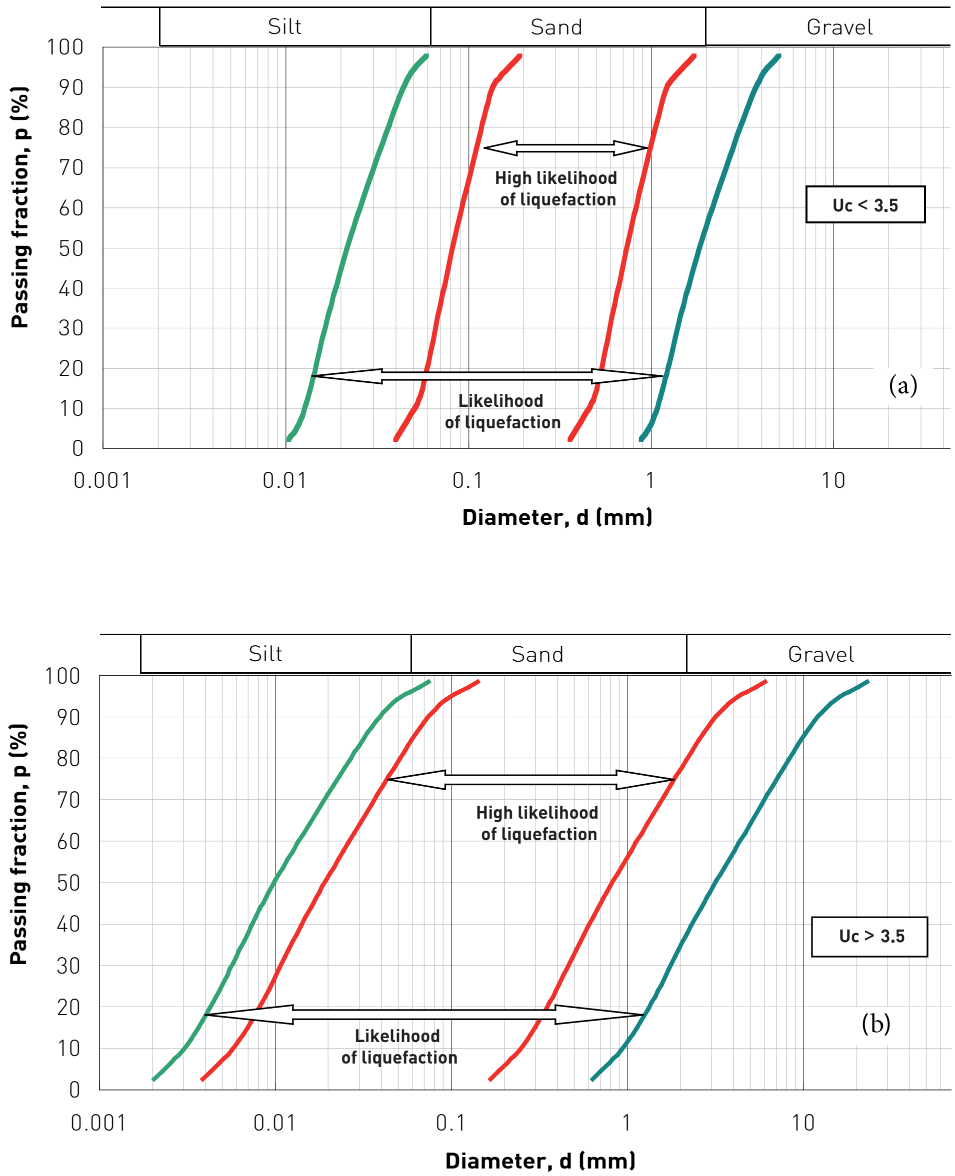
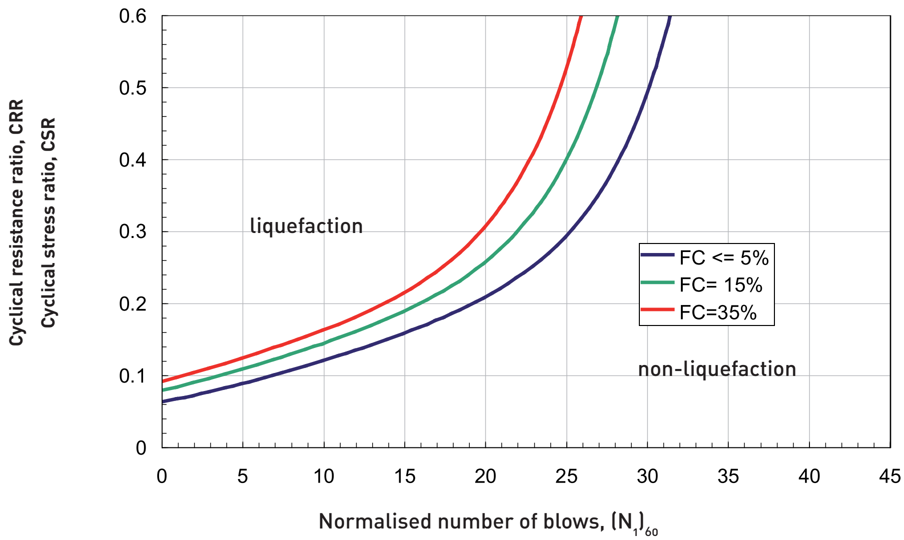


Figure 2.7-1 – Grain sizes for preliminary assessment of the liquefaction susceptibility of a soil (soils of uniform grain size (a) and extended grain size (b)) (from AGI, 2005).



$$(N_1)_{60} = N_{SPT}\, C_N\, C_E\, C_B\, C_R\, C_S$$

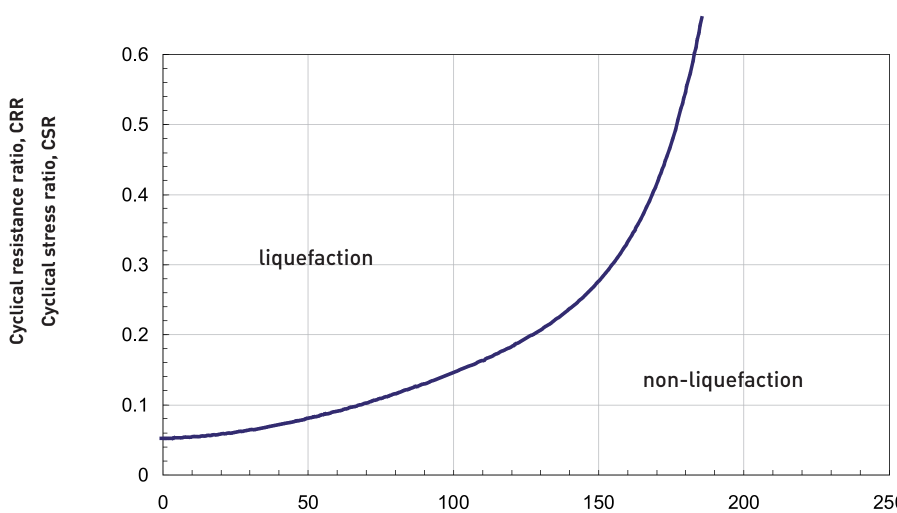
where:

$$C_N = \left(\frac{p_a}{\sigma'}\right)^{0.784-0.0768\sqrt{(N_1)_{60}}}$$

C_N should not exceed 1.7

p_a (atmospheric pressure ≅ 100 kPa) and σ'_V are expressed in the same unit of measurement

$C_E C_B C_R C_S \approx 1$

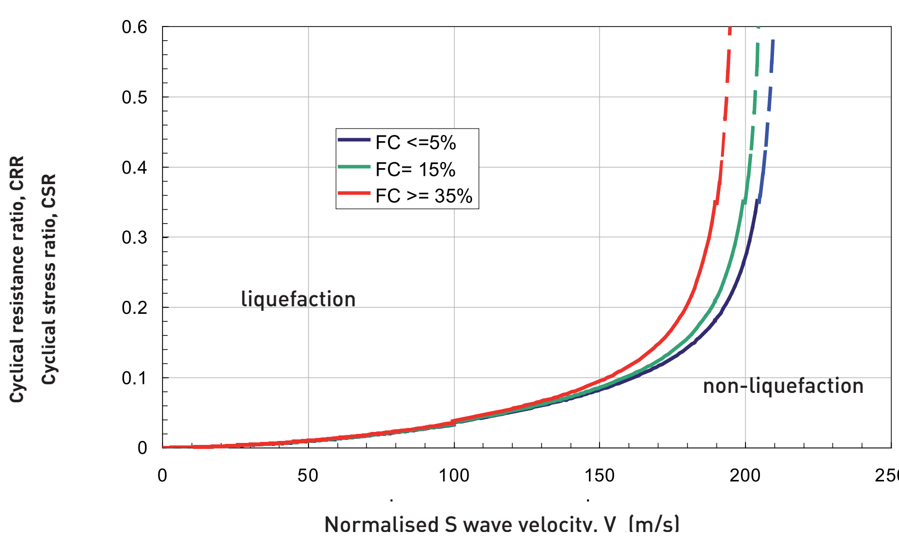


$$q_{c1N} = C_Q \frac{q_c}{p_a}$$

where:

p_a (reference atmospheric pressure ≅ 100 kPa) and σ'_V are expressed in the same unit of measurement

$$C_Q = \left(\frac{p_a}{\sigma'_v}\right)^{1.338-0.294(q_{c1N})^{0.264}}$$



$$V_{s1} = C_V V_s$$

where:

p_a (reference atmospheric pressure ≈ 100 kPa) and σ'_V are expressed in the same unit of measurement

$$C_V = \left(\frac{p_a}{\sigma'_v}\right)^{0.25}$$

Figure 2.7-2 – Maps for estimating the normalised liquefaction resistance *CRR* of a saturated sandy soil vs. the percentage of the fine fraction FC on the basis of corrected values of N_{SPT} q_c and V_s

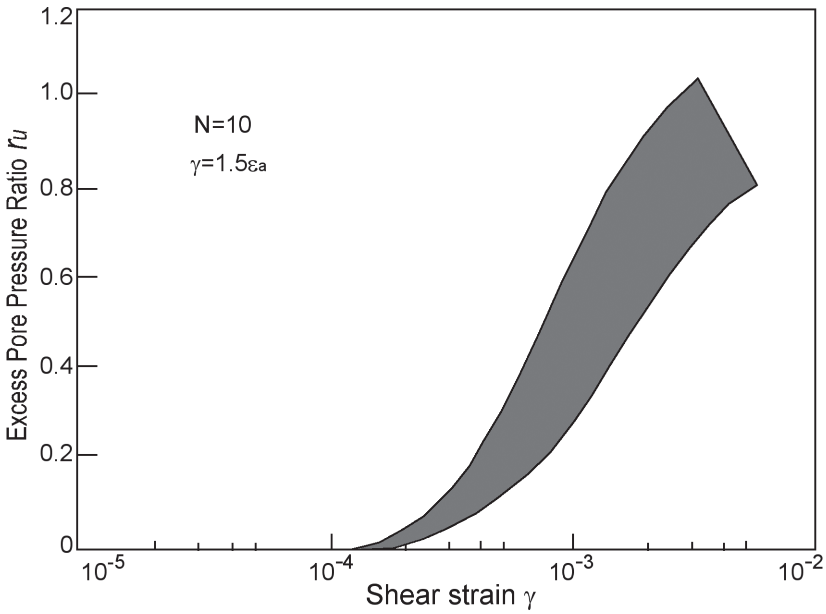


Figure 2.7-3 – Pore pressure ratio ru vs. maximum shear deformation induced by the earthquake

$$\gamma_{max} = 0.65 \frac{a_{max\ s}}{g} \sigma_v r_d \frac{1}{G}$$

from Seed & Idriss (1982).

Table 2.7-1 – Magnitude Scaling Factor - MSF (Seed & Idriss, 1982).

Magnitudo	MSF
5.5	1.43
6.0	1.32
6.5	1.19

Table 2.7-2 – Pore pressure ratio $r_u = \frac{\Delta u}{\sigma'_0}$ in funzione di γ_{max}

γ_{max} [%]	r_u
5×10^{-2}	0.2
1×10^{-1}	0.4
2×10^{-1}	0.6
4×10^{-1}	0.8
5×10^{-1}	0.95

Table 2.7-3 – Shear modulus *G* reduction factor in the first 20 m vs. the acceleration $a_{max\ s}$

$a_{max\ s}$ [g]	G/G_0
0.10	0.80
0.20	0.50
0.30	0.35
0.40	0.28

2.8 Estimating Expected Magnitude as Part of Analyses in Instability-Prone Zones

2.8.1 FOREWORD

Verifications of liquefaction (Chapter 2.7) and slope stability (Chapter 2.6), must take into account the expected magnitude of an earthquake. In liquefaction verifications, the value of M determines:

- whether the verification (together with other conditions) may be neglected;
- the value of the *MSF* (Magnitude Scaling Factor), which corrects the value of the *CRR-CSR* ratio to determine the current safety factor.

In slope stability verifications, the values of M and of the epicentral distance (*R*) are used in empirical correlations that define: the critical seismic coefficient for soil slopes; the average number of rock falls per site for rock slides.

Magnitude calculations are required because the higher the magnitude, the higher the released energy and, hence, the capability of inducing soil deformation cycles significant in number and amplitude to give rise to neutral overpressures and liquefaction. For the same reasons, high-magnitude events may produce pulses that may in turn impart high kinetic energies to portions of the soil or rock, to produce phenomena of instability.

2.8.2 MAGNITUDE ASSESSMENT

Magnitude represents a highly important value for defining seismic hazard and thus seismic action. The randomness of this value is reflected in its use in seismic hazard studies. The same character should be conserved when it is employed for design purposes or SM studies.

The following method is a simple and safety-oriented method for estimating the magnitude value to be considered in successive assessments, preferably for verifications of liquefaction in a particular study area or micro-zone:

1. Always consider the seismogenic zoning (ZS9) (Figure 2.8-1), according to which seismicity may be distributed in 36 zones, each associated with a maximum magnitude M_{wmax}[50].
2. For sites falling within one of the aforementioned 36 seismogenic zones M_{wmax} is assumed to be equivalent to the value of M (Table 2.8-1).
3. For verifying liquefaction and for sites not falling within any of the 36 seismogenic zones, determine the minimum distances (R_i) from the surrounding zones (*i*) and, for each of them, check whether the magnitude Mi of the zone is lower than that provided by the formula M_s = 1+3log(*R*). When lower, then liquefaction verification is not necessary; when verification is necessary, select the highest value of M_i from among those requiring verification.
4. For slope stability verification, when using Romeo's (2000) semi-empirical formula, consider, the most severe values deriving from the application of all M_i,R_i pairs inferred from the seismogenic zones lying near the study area.

50 The data are provided in terms of moment magnitude M_w. They may also be expressed in other magnitude scales by using the correlation described in *Gruppo di lavoro* (2004). In particular, this should be done to verify the distance at which the risk of liquefaction, expressed in Ms, may be considered to be zero.

Table 2.8-1 – Values of M_{wmax} for the seismogenic zones of ZS9 (from Gruppo di lavoro, 2004)

ZS Name	ZS Number	M_{wmax}
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/Abruzzi area, Umbrian Apennines, Nice, Sanremo	918, 919, 910	6.37
Friuli-Eastern Veneto, Garda-Verona area, Garfagnagna-Mugello, Ionian Calabria	905, 906, 915, 930	6.60
Molise-Gargano, Ofanto, Channel of Otranto	924, 925, 931	6.83
Abruzzi Apennines, Sannio-Irpinia-Basilicata	923, 927	7.06
Tyrrhenian Calabria, Hyblaean Mountains	929, 935	7.29

The second method permits the estimation of a reference magnitude-distance pair (hereafter called "M-R") for any site; this M-R pair will be preferably adopted for slope instability assessments.

The M-R pairs typical to each site are determined using the results of the regional hazard studies developed by the "Istituto nazionale di geofisica e vulcanologia" (INGV - National Institute of Geophysics and Volcanology) (Gruppo di lavoro, 2004) as part of the national reference map building process[51].

Initial information was provided by the national seismogenic zoning (ZS9) map, according to which seismicity may be distributed in 36 zones (Figure 2.8-1), each associated with a magnitude recurrence law[52].

The results provided by the INGV study (Spallarossa & Barani, 2007) also include the disaggregation (or de-aggregation) of seismic hazard (Bazzurro & Cornell, 1999): this operation consents the evaluation of contributions from different seismic sources to the hazard level of a given site. The most common form of disaggregation occurs in the two dimensions of magnitude and distance (M-R), which allows for the definition of seismogenic sources at a distance R and capable of generating earthquakes of a magnitude M. The seismic hazard maps were built in terms of median of the distribution of hazard values obtained with different logical trees. Therefore, the input data for the disaggregation were the models and parameter values along a single branch of the logical tree; this branch corresponds to the hazard values closest to the median. The result is given for 9 return periods (RP): 30, 50, 72, 100, 140, 200, 475, 1000 and 2500 years.

Average -and $\overline{M}$-$\overline{R}$ modal (M^*-R^*)[53] values may be obtained by disaggregating the peak ground acceleration of stiff soil (a_g) with a 10% probability of exceedance in 50 years (Spallarossa & Barani, 2007) or with other probabilities of exceedance depending on the other purposes of the assessment. The

51 These studies provided hazard parameter values for using points distributed along a regular grid of geographic coordinates.

52 The data are provided in terms of moment magnitude Mw. They may also be expressed in other magnitude scales by using the correlation reported by the Working Group (2004).

53 The average value is obtained as the weighted average of the magnitudes, where the weight of each value is given by the contribution that the magnitude provides to the hazard level. The modal value M* is the value of M with the highest contribution to the hazard level.

Comuni_MR Table (see the enclosed DVD)* lists the average and modal values for each Municipality; the maximum values are assigned to points along the grid falling within the municipal territory, or to the point along the grid closest to the municipal border.

These values are plotted in Figures 2.8-2, 2.8-3, 2.8-4, 2.8-5 and 2.8-6.

The results illustrated in the map may be used to verify slope stability or liquefaction conditions for buildings or structures associated with a reference period (RP) that does not exceed that used to develop the map.

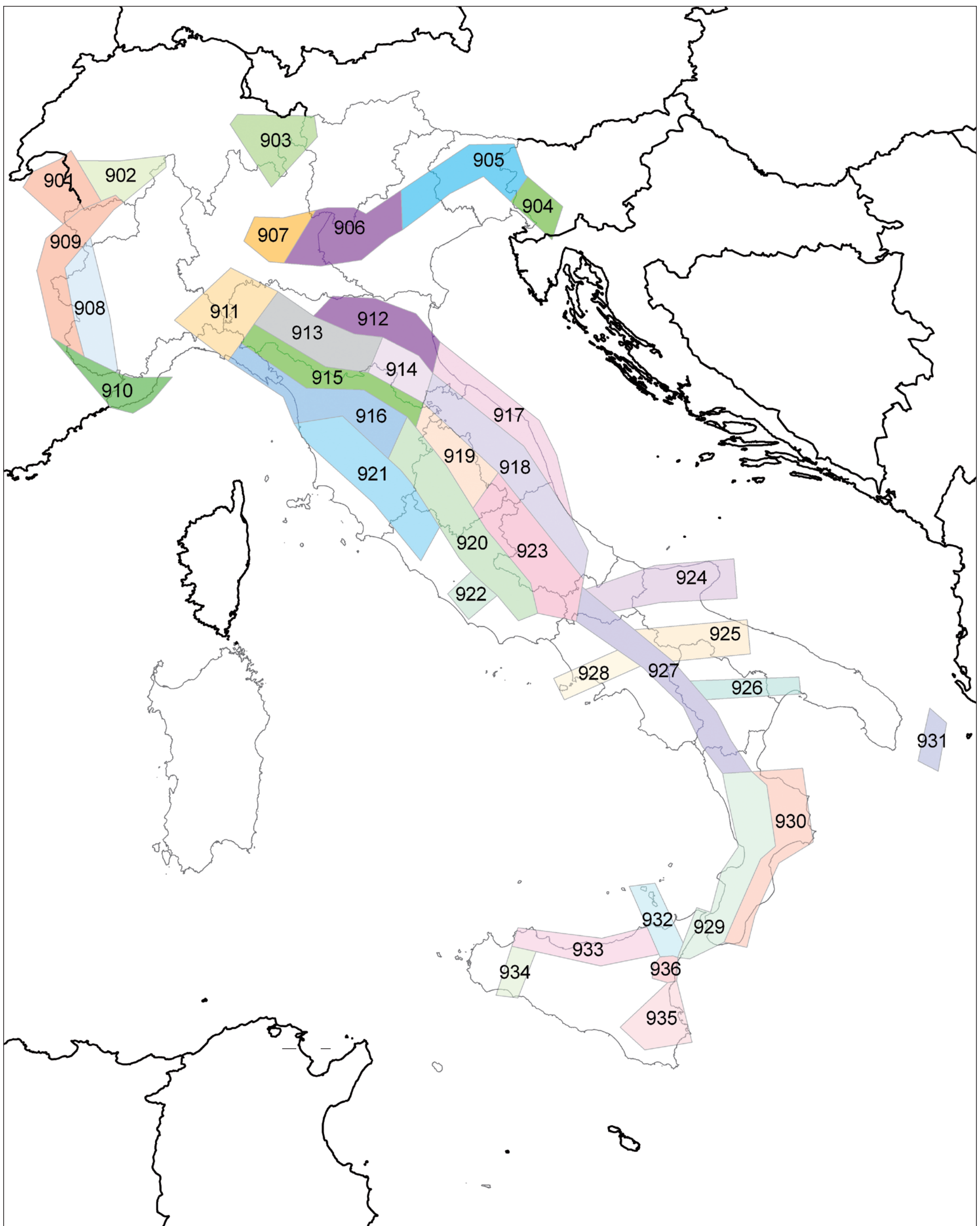


Figure 2.8-1 – Seismogenic zones for the reference regional seismic hazard map (Gruppo di lavoro, 2004).

* Not included in the english edition.

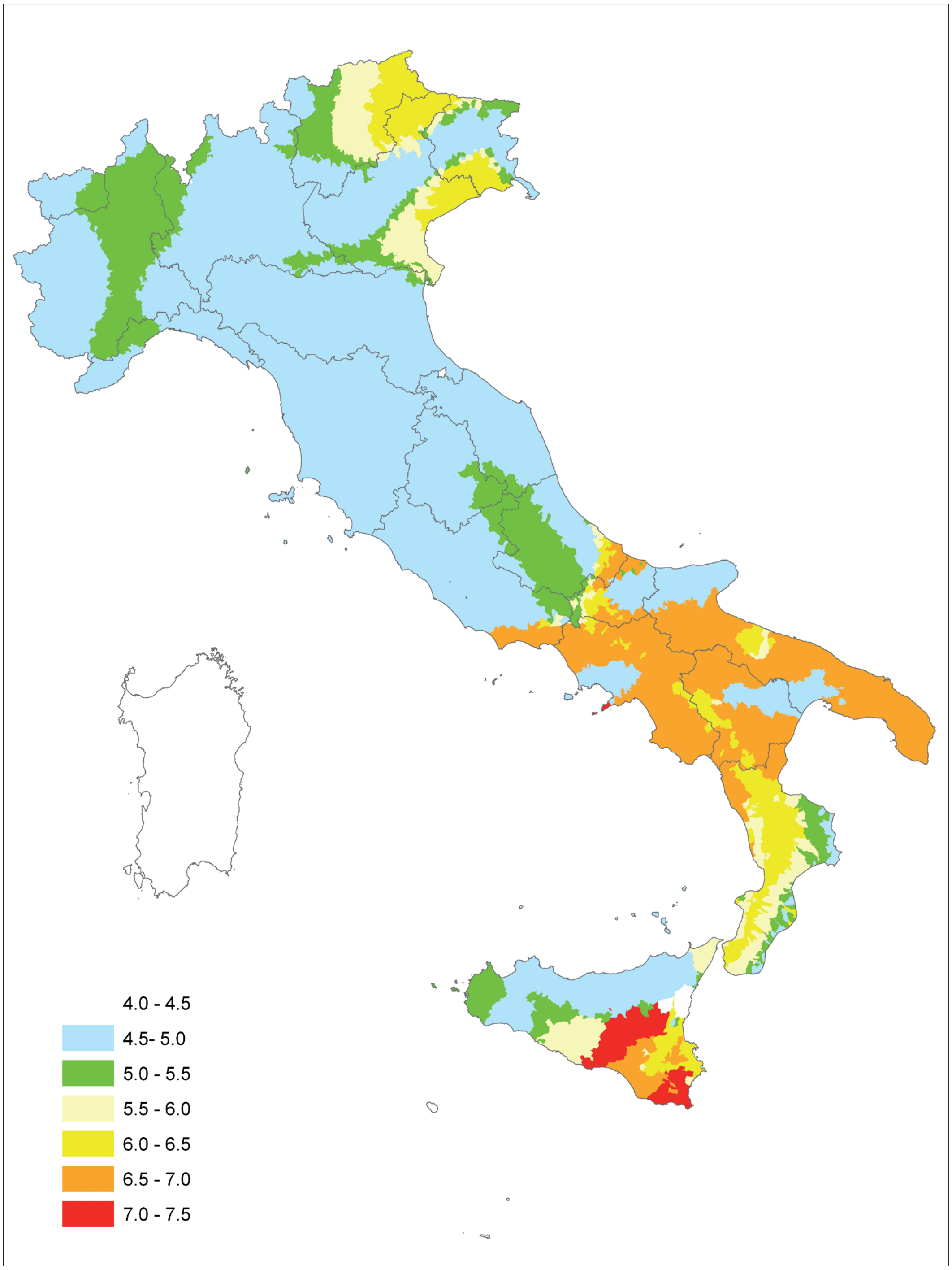


Figure 2.8-2 – Modal values of M for each Municipality, obtained by disaggregating the hazard with return periods of 475 years (processing of data from Spallarossa & Barani, 2007).

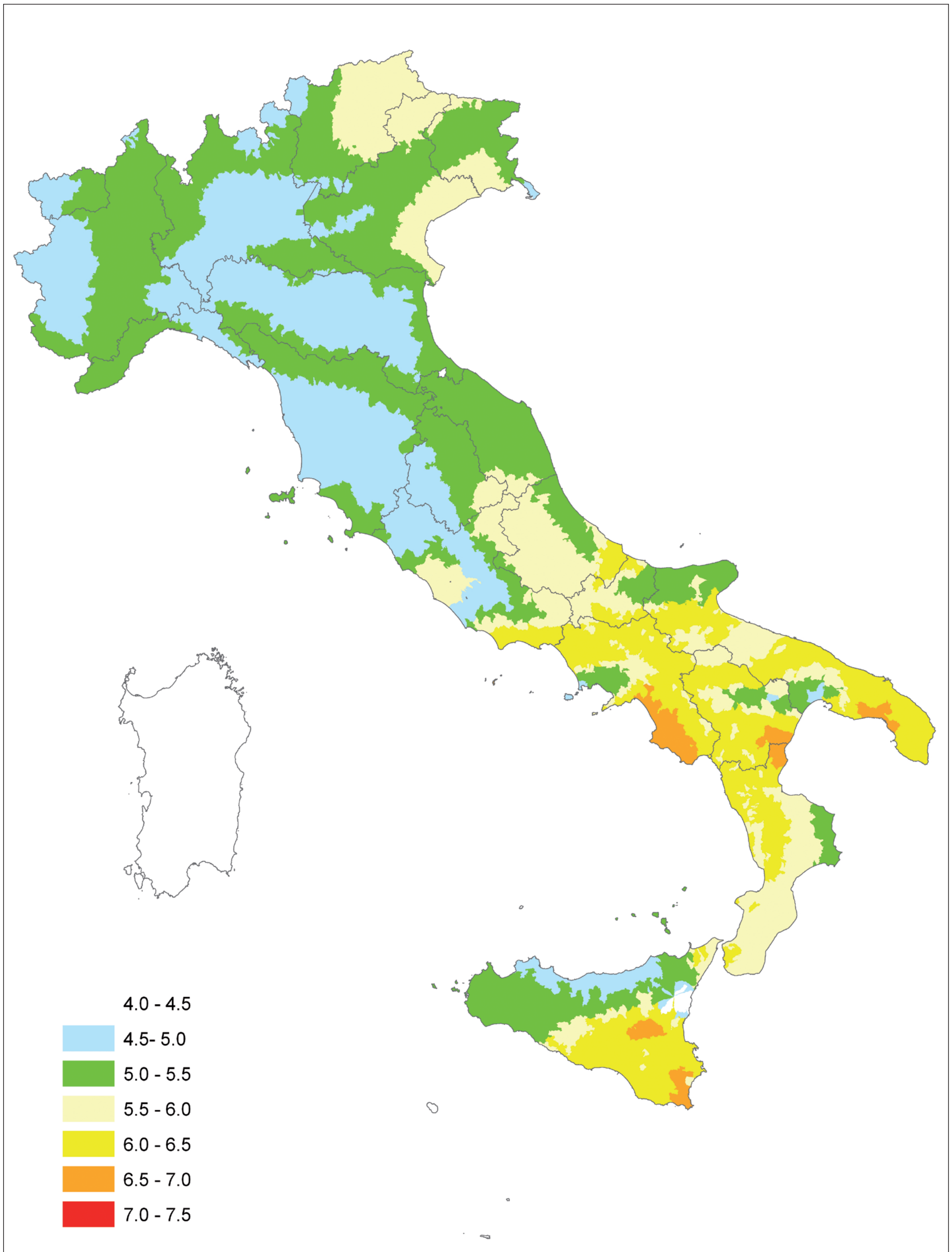


Figure 2.8-3 – Modal values of M for each Municipality, obtained by disaggregating the hazard with return periods of 475 years (processing of data from Spallarossa & Barani, 2007).

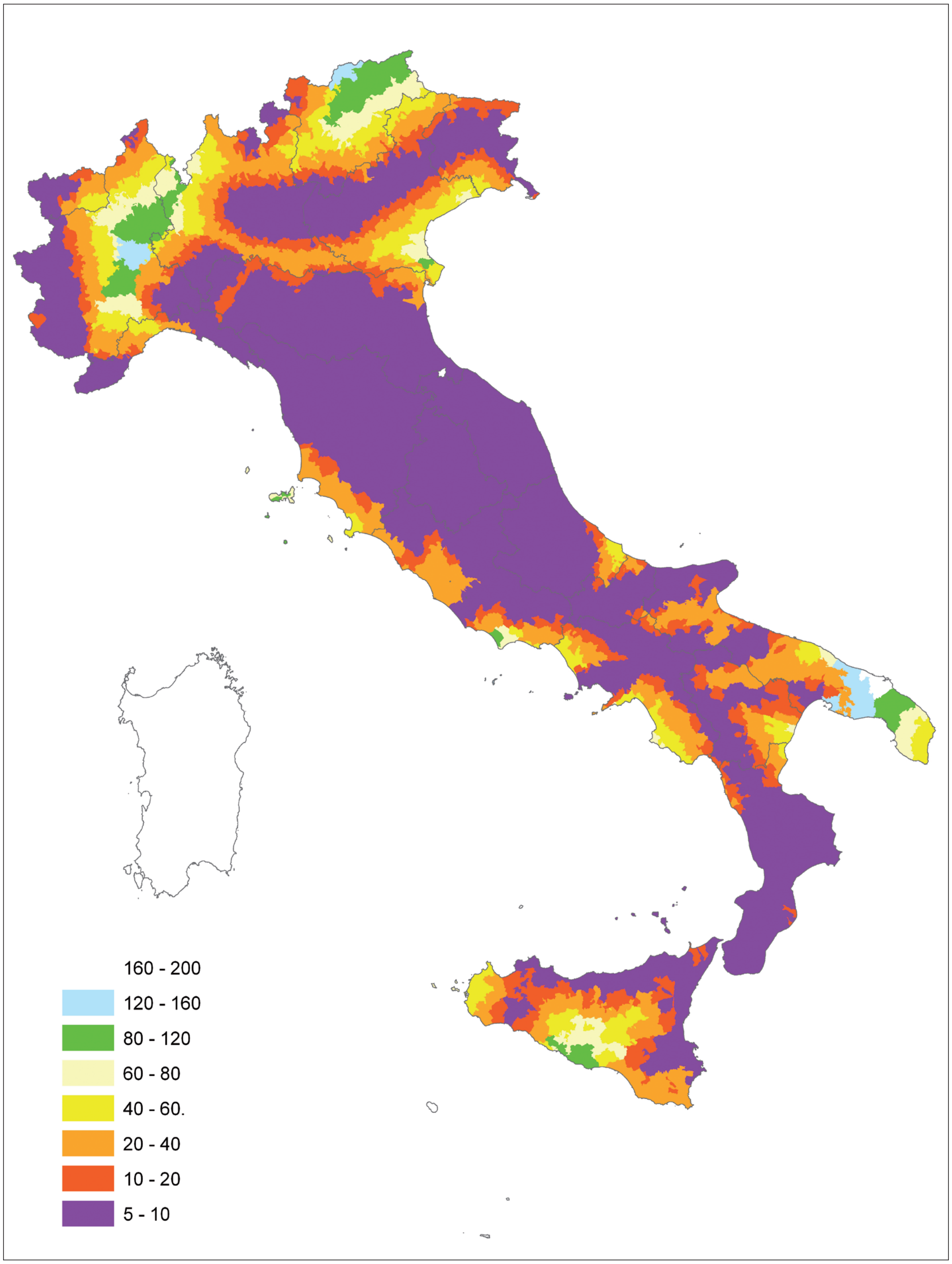


Figure 2.8-4 – Modal values of R for each Municipality, obtained by disaggregating the hazard with return periods of 475 years (processing of data from Spallarossa & Barani, 2007).

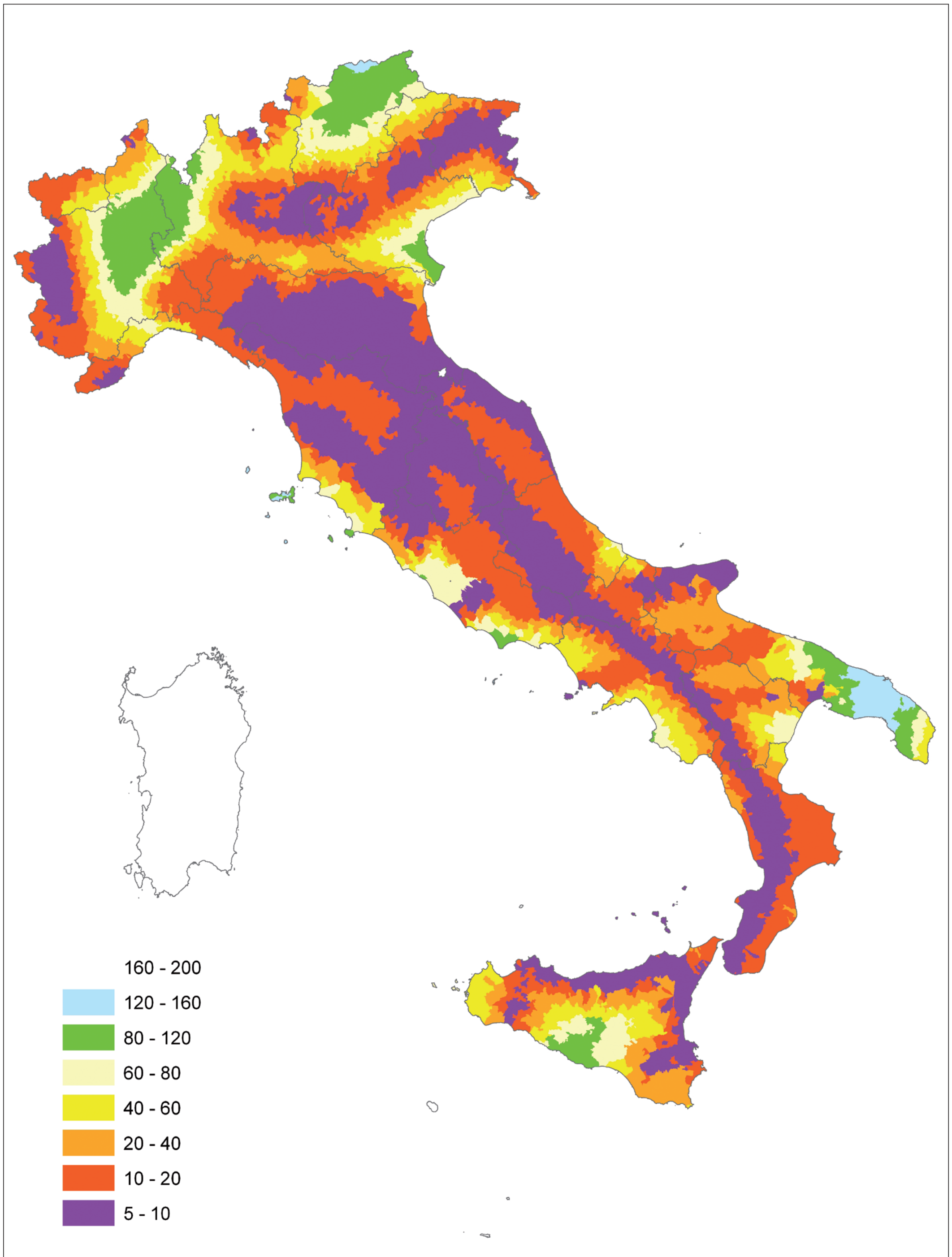


Figure 2.8-5 – Modal values of R for each Municipality, obtained by disaggregating the hazard with return periods of 475 years (processing of data from Spallarossa & Barani, 2007).

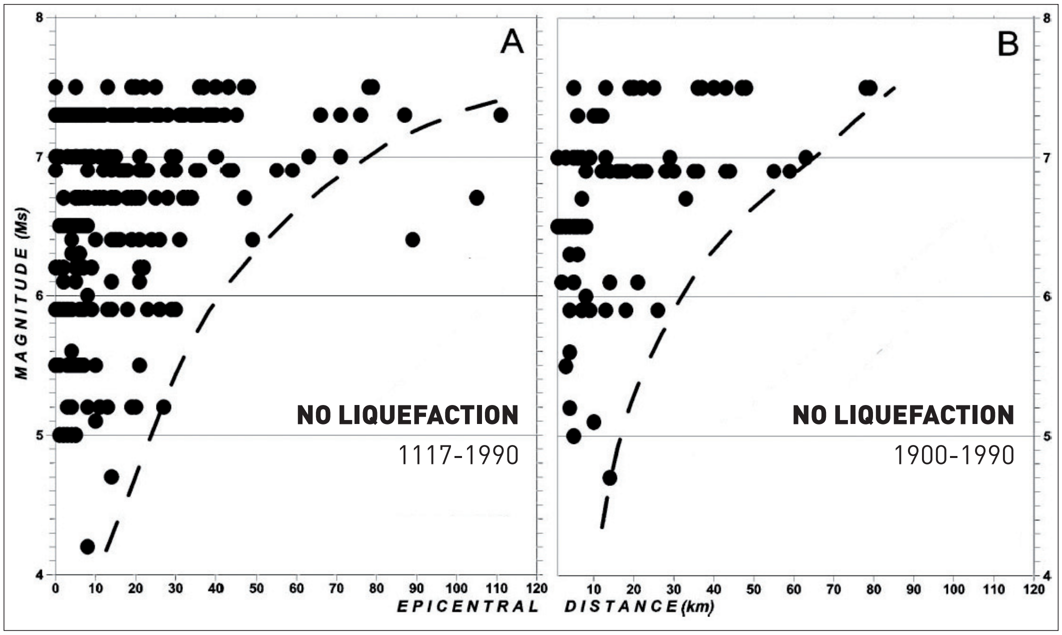


Figure 2.8-6 – Observed liquefaction phenomena in terms of M_s and epicentral distance (from Galli, 2000)

2.8.3 BIBLIOGRAPHIC REFERENCES

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Contents of the DVD*

- **Guidelines for Seismic Microzonation**
  - Instructions and Criteria – Guidelines
  - Appendix
  - Glossary
  - Examples of Maps
- **Geographic Information System**
  - Municipal Data
  - ArcReader Installation
  - ArcReader Tutorial
- **Database**
  - Accelerograms
  - Decay Curves
  - Hazard
  - Vulnerability/Exposure
    - Summary Tables
    - Municipal Data
  - Risk
- **Note on the contents of the DVD**

The DVD contains the Guidelines for Seismic Microzonation prepared by the ad-hoc Gruppo di lavoro (Working Group) established by the Conference of Regions and Autonomous Provinces of Italy and by the Civil Protection Department (Presidency of the Council of Ministers). The DVD also contains: the accelerograms and decay curves used in the preparation of the schedules of stratigraphic amplification factors; the maximum values of the spectral ordinates and parameters specified by the National Building Code (ag, F0 and Tc) for Municipalities and built-up areas for various return periods; the average and modal values of M and R (magnitude and distance) obtained from hazard disaggregation; basic municipal data on vulnerability and exposure (housing and resident population) processed from the 2001 ISTAT Census; seismic zones and municipal risk indexes. The ArcReader program enables users to search and download the various databases, as well as to display and query the maps of municipal borders.

Internet resources: http://www.protezionecivile.gov.it/jcms/it/view_pub.wp?contentId=PUB1137
http://www.centromicrozonazionesismica.it/it/download/category/3-linee-guida

* Not included in the english edition.

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