Republic of Turkey
Ministry of Public Works and Settlement

General Directorate of Disaster Affairs

Seismic Microzonation for Municipalities

Manual

January 2004

Prepared by:

DRM
world institute for
disaster risk management

With financial support from:

DEZA DIREKTION FÜR ENTWICKLUNG UND ZUSAMMENARBEIT
DDC DIRECTION DU DÉVELOPPEMENT ET DE LA COOPÉRATION
DSC DIREZIONE DELLO SVILUPPO E DELLA COOPERAZIONE
SDC SWISS AGENCY FOR DEVELOPMENT AND COOPERATION
COSUDE AGENCIA SUIZA PARA EL DESARROLLO Y LA COOPERACIÓN

Seismic Microzonation for Municipalities

This documentation is the result of a collaborative effort, led by the World Institute for Disaster Risk Management, Inc. (DRM) and the General Directorate of Disaster Affairs (GDDA), Ministry of Public Works and Settlement, Republic of Turkey, and financed by the Swiss Agency for Development and Cooperation (SDC) of the Federal Department of Foreign Affairs.

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General Directorate of Disaster Affairs, Ministry of Public Works and Settlement (GDDA); Bogazici University, Kandilli Observatory and Earthquake Research Institute (BU-KOERI), Istanbul; Middle East Technical University (METU), Ankara; Sakarya University (SAU), Adapazari; Swiss Federal Institute of Technology Zurich - Institute for Geotechnical Engineering (ETHZ-IGT); Swiss Federal Institute of Technology Zurich - Institute of Geophysics (ETHZ-IG); Swiss Federal Institute of Technology Lausanne - Institut de Structures (EPFL-IS); Swiss Federal Institute for Snow and Avalanche Research (SLF), Davos; Studer Engineering, Zurich; Virginia Institute of Technology and State University (VT), College of Architecture and Urban Studies; University of Pennsylvania (UP), Wharton School - Risk Management and Decision Processes Center.

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Citation: World Institute for Disaster Risk Management, Inc., 2004: Seismic Microzonation for Municipalities. Manual.

www.DRMonline.net

January 2004

Foreword

The Kocaeli Earthquake of August 17, 1999 revealed the devastating consequences that earthquakes can have for society and economy. In the aftermath of this earthquake, the General Directorate of Disaster Affairs started initiatives with the objective to mitigate the earthquake risk in Turkey.

The General Directorate of Disaster Affairs (GDDA), Ministry of Public Works and Settlement, undertook an endeavor entitled "Microzonation for Earthquake Risk Mitigation" (MERM).

The World Institute for Disaster Risk Management, Inc. (DRM) executed the project with financial support from the Swiss Agency for Development and Cooperation (SDC), of the Federal Department of Foreign Affairs, Switzerland.

Project design commenced in September 1999. The project was executed between March 2002 and February 2004.

This endeavor resulted in the following project documentation, under the generic title of "Seismic Microzonation for Municipalities": (1) Executive Summary; (2) Manual; and, (3) Reference information, consisting of pilot studies, a state-of-the-art report, and supporting documentation for sustainable implementation.

DRM executed the MERM Project with Turkish and international participation:

Bogazici University, Kandilli Observatory and Earthquake Research Institute (BU-KOERI), Istanbul; Middle East Technical University (METU), Ankara; Sakarya University (SAU), Adapazari; Swiss Federal Institute of Technology Zurich - Institute for Geotechnical Engineering (ETHZ-IGT); Swiss Federal Institute of Technology Zurich - Institute of Geophysics (ETHZ-IG); Swiss Federal Institute of Technology Lausanne - Institut de Structures (EPFL-IS); Swiss Federal Institute for Snow and Avalanche Research (SLF), Davos; Studer Engineering, Zurich; Virginia Institute of Technology and State University (VT), College of Architecture and Urban Studies; University of Pennsylvania (UP), Wharton School - Risk Management and Decision Processes Center.

The present document is entitled "Manual." It describes in three chapters the proposed methodology for seismic microzonation studies in Turkey:

First chapter: Overview of the methodology, definition of terms in earthquake engineering, and description of the principal earthquake effects.

Second chapter: Description of the seismic microzonation procedure, including data acquisition, map preparation and recommendations for zone-associated building regulations. This chapter is directed to the commissioned enterprises.

Third chapter: Provides guidance for the application of microzonation maps in the process of municipal land use management. This chapter is directed to municipal planners and officials.

Acknowledgements

A project of such dimensions, involving local and governmental authorities as well as several university institutions of worldwide reputation, and consisting of intensely interconnected tasks, can only be accomplished with the volition of all involved parties. Special thanks must be given to:

- The General Directorate of Disaster Affairs (GDDA), General Director Dr. Mustafa Taymaz, former Deputy General Director Ekrem Demirbas, Oktay Gökçe and the staff of GDDA for their cooperation in the development and implementation of the project.
- The Swiss Agency for Development and Cooperation (SDC) of the Federal Department of Foreign Affairs for funding the project, and for valuable contributions towards the improvement of project sustainability and implementation, in particular by Ms. Barbara Dätwyler and Dr. Franz Stössel.
- The Governors of the provinces of Kocaeli and Sakarya, as well as the authorities of the municipalities involved in the pilot studies, for their assistance given to the project team.
- The President of Sakarya University, Prof. Mehmet Durman, for helping the project in all stages with great effort.
- The members of the Technical Advisory Board for their comments on the manual, making it possible to achieve an international standard that includes state-of-the-art methodologies based on latest research results.
- All members of the project team for the constancy shown in the preparation of the assigned tasks.

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1. Definitions and General Methodology

1.1 General

Scope of the Microzonation Manual

Microzonation has to be performed in municipalities with more than 30,000 inhabitants.

The purpose of the Seismic Microzonation Manual is to illustrate a microzonation methodology developed for Turkey.

Microzonation is an efficient tool to mitigate the earthquake risk by hazard-related land use management. Microzonation does not replace the existing Turkish building and construction codes.

This manual has different purposes for specific Turkish authorities, public and private enterprises:

- It should advise the responsible government agencies on how to review and evaluate microzonation studies in Turkey performed by private or public enterprises;
- It should inform municipal authorities about the required inputs for and outputs from a microzonation project;
- It should define technical recommendations for private or public companies commissioned with the execution of a microzonation project.

Content of the Seismic Microzonation Manual

This manual consists of three chapters:

- Chapter 1 is directed to the general audience (approving agency, municipalities, commissioned enterprise, public). It gives general definitions of terms used in this document and characterizes earthquake effects to be taken into account when performing a microzonation project. It also describes in general the microzonation method developed, its relation to the Turkish Building Code, the investigations needed to perform such a microzonation and how to interpret the different microzonation maps in order to develop corresponding building regulations;

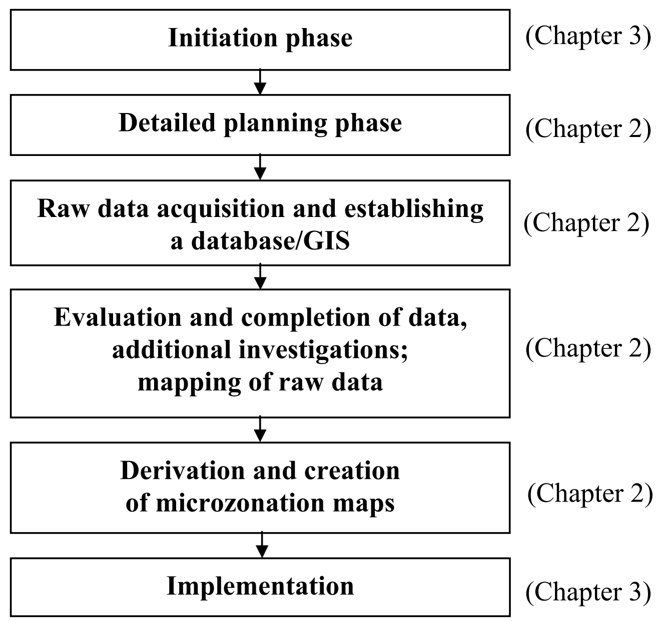
- Chapter 2 is mainly directed to the enterprise commissioned to perform the microzonation study. It gives practical and technical guidelines as well as recommendations to perform the microzonation method described in Chapter 1 efficiently;

- Chapter 3 describes the tasks and responsibilities of the municipalities commissioning microzonation studies and implementing the results of these studies into their land use management system.

Phases of the Microzonation Process

It is recommended that the project phases mentioned below be followed. Technical details for each step are given in Chapter 2 and Chapter 3.

- Initiation phase within the municipal administration. Details are described in Chapter 3. (Implementation of microzonation studies in land use management plans of a municipality).
- Detailed project planning phase by commissioned enterprises
- Raw data acquisition and establishing a database/GIS
- Evaluation and completion of data, additional investigations; mapping of raw data
- Derivation and creation of microzonation maps
- Implementation (Details are described in Chapter 3)



Basic Principles

The microzonation procedures should be adjusted to the development of the state of technology at regular time intervals, with special consulting support.

The results of the microzonation projects have to be submitted by the municipality to the responsible government agency for approval. For details, see Chapter 3.

Microzonation of municipal districts has to be reviewed and revised appropriately:

- After an earthquake affecting the municipal districts, by taking the damage pattern in the municipal districts into account.
- Every 15 years, taking the accumulated new geological, geophysical and geotechnical data and the new state of technology into account.

It is recommended that municipalities collect all geotechnical, geophysical and geological data resulting from the ongoing building activities from their territory. These data can be used for the enhancement and update of the individual microzonation maps. For details, see Chapter 3.

1.2 Definitions and Phenomenology

1.2.1 Definitions of Terms

Definition of Hazard, Vulnerability and Risk

Earthquake hazard is anything associated with an earthquake that may affect the normal activities of people. This includes surface faulting, ground shaking, landslides, liquefaction, tectonic deformation, tsunamis, seiches and other earthquake-related hazards.

Vulnerability of structures and installations/equipment is their susceptibility to damage during an earthquake.

The vulnerability of a structure depends mainly on:
- size
- mass
- structure layout
- irregularities
- material types
- construction details.

The **vulnerability of municipalities** depends on the vulnerability of infrastructure and redundancies within infrastructure.

Earthquake risk is the building damage, number of people that are hurt or killed, and further economic losses in a certain time period, due to an earthquake with a return period corresponding to this time period. Earthquake risk can be expressed, based on the definitions above, as:

"<u>Earthquake Risk = Earthquake Hazard*Vulnerability*Value at Risk</u>".

Indirect losses, in particular economic losses, due to the temporary stop of economic activity, play an increasing importance. They also need to be considered when assessing the risk.

The above definitions for a single earthquake can be expanded to take into account all possible earthquakes, each with an appropriate likelihood.

Zoning, Macrozoning

Earthquake zoning is the identification of zones of similar levels of earthquake hazard.

If the earthquake zoning is done on a national scale (e.g. in most national codes, including the Turkish Building Code of 1997), it is also called **macrozoning.**

Macrozoning is based on the typical earthquake-shaking hazard for specific regions. The earthquake hazard is computed with probabilistic models, which take the distribution of potentially active faults into account, as well as catalogues of observed and recorded earthquake events and most suitable attenuation laws.

Macrozonation maps present earthquake hazard for some defined soil or rock conditions. But the local soil conditions are not taken into account, since small-scale maps cannot deal with these details.

Microzoning, Earthquake Effects

Microzonation is the identification of separate areas having different potentials for hazardous earthquake effects. Microzonation, as is defined and assessed in this Manual, will primarily serve for land use management and city planning.

Microzonation should encompass the variations in:

- Earthquake hazard parameters;
- Surface faulting and tectonic deformation**;**
- Ground shaking intensity**;**
- Liquefaction, ground spreading and settlement susceptibility**;**
- Slope stability problems like landslides or rock falls**;**
- Earthquake-related flooding due to tsunamis, seiches or ground settlements**.**

These effects are treated more precisely in Chapter 1.2.6.

Need of Specific Studies

In order to be able to assess the above-mentioned effects for a region selected for microzonation, sufficiently detailed seismological, geophysical, geological and geotechnical investigations have to be conducted. For this purpose, accurate results are needed. The minimum requirements for these investigations are given in Chapter 2.

Definitions for Strength of Earthquakes

The strength of an earthquake is generally measured in two ways, based on two different approaches:

- The **magnitude** of an earthquake event is a quantity defining the energy released by this event (in form of earthquake waves), and is calculated from recorded seismograms.

- The **intensity** of an earthquake event is a quantity defining the severity of ground shaking on the basis of observed effects in a limited area.

As a tool to define the different intensity levels, it is recommended that the European Macroseismic Scale (EMS-98) be used. This scale is compatible with the older MSK (Medvedev Sponheur Karnik) scales, but also takes new building types with earthquake-resistant design into account. This scale is briefly introduced here:

- The EMS-98 defines twelve intensity degrees from intensity I to intensity XII.
- The major difference between the EMS-98 and other intensity scales is in the detail with which the different terms adopted are defined at the outset, in particular, building types, damage grades, and quantities, and these are considered individually.
- The EMS-98 relates **intensity** at a place with the **damage grade** of a specific structure, which is dependent on the vulnerability of this structure. In EMS-98, **vulnerability classes** for corresponding building types are introduced for this purpose.

More details on the EMS-98 are given in Chapter 2.

Definition of Terms in Risk Reduction

Earthquake Preparedness includes all organizational measures taken before an earthquake event, in order to be ready to act properly in case of a major earthquake. Earthquake preparedness includes the following main fields:

- Preparedness of intervention forces (e.g. fire departments, police, emergency hospitals)
  - Organization, who does what (coordination, knowing what to do)
  - Equipment (e.g. first aid, fire extinguishers)
  - Supplies (e.g. water, food)
  - Etc.
- Utilities (water, energy, transportation etc.)
  - Organization, who does what (coordination, knowing what to do)
  - Equipment (e.g. repair material)
  - Etc.

Appropriate checklists can be a valuable help for ensuring appropriate earthquake preparedness.

Prevention includes all measures taken before an earthquake event in order to reduce the earthquake risk. Since the earthquake hazard can not be influenced, prevention measures include:

- Land use management, taking into account local earthquake hazard.
- Reduction of the vulnerability of structures and facilities (particularly important for critical infrastructure)
- Reduction of the value at risk.

1.2.2 Relationship to the Turkish Building Code

Relationship to the Turkish Building Code

The zone map of the Turkish Earthquake Code represents the hazard calculated for building design and construction, whereas the microzonation takes the regional earthquake hazard, the local geological and topographical conditions into account, particularly also the unfavorable ones.

- The zoning map of the Turkish Building Code shows the different macrozones of Turkey, for which minimum effective acceleration coefficients and corresponding design spectra are defined in the Turkish Building Code.
- As **land use management tool**, microzonation shows the relative earthquake hazard in a particular area.
- There is no relationship between the Turkish Earthquake Code and microzonation. **The Turkish Building Code has always to be respected as a minimum requirement**. If specific site investigations lead to higher design spectra than the spectra in the Turkish Code, it is recommended that these design spectra instead of those from the Turkish Building Code be used.

1.2.3 Content of Final Microzonation Maps

Types of Microzonation Maps

The following maps are part of the microzonation:
- Surface faulting map
- Ground shaking map
- Liquefaction susceptibility map
- Landslide hazard map
- Optional, where appropriate: earthquake-related hazard flooding map or other regional maps of earthquake-related hazards

Surface Faulting Map

Content of the surface faulting map:
- Active fault zones where surface faulting has been observed several times in the project area. (two different zones: high/none)
- Where appropriate, recommendations for zone-specific building regulations

Ground Shaking

Content of the ground shaking map:
- Three different relative shaking intensity zones: (high/moderate/low)
- Where appropriate, recommendations for zone specific building regulations

Liquefaction Susceptibility

Content of the liquefaction susceptibility map:
- Liquefaction susceptibility, with characterization of three susceptibility classes (high/moderate/low susceptibility)
- Where appropriate, recommendations for zone specific building regulations

Landslides, Rock Fall

Content of the landslides and rock fall hazard map:
- Landslide hazard, with characterization of three hazard classes (high/moderate/low hazard)
- Where appropriate, recommendations for zone specific building regulations

Earthquake-related Flooding

Content of the earthquake-related flooding hazard map:
- Earthquake-related flooding hazard, with characterization of two hazard classes (high/low hazard)
- Where appropriate, recommendations for zone specific building regulations

1.2.4 Principles of Mapping

General Information

A map scale specifies the amount of reduction between the real world and its graphic representation (usually a paper map). It is usually expressed as the ratio between a sample length of its graphic representation and the corresponding real length of this sample.

Map scales can roughly be divided into three groups:

- Large scale maps: 1:25,000 or larger
- Medium scale maps: 1:1,000,000 to 1:25,000
- Small scale maps: 1:1,000,000 or smaller

For the purpose of microzonation, only large-scale maps are relevant. Topographic maps, with scales of 1:5,000, are basic requirements for the microzonation work.

Typical Scales for Microzonation

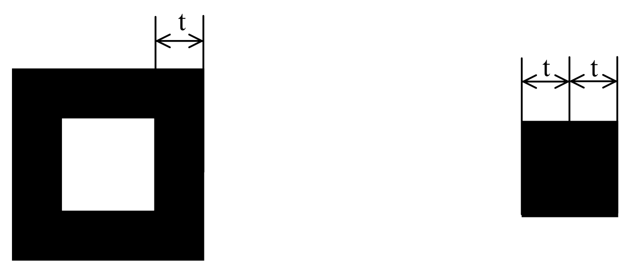
Typical scales for resulting microzonation maps are of the order of 1:5,000, in special cases the scale may go up to 1:1,000.

In Turkey, city plans are at a scale of 1:1,000. For practical reasons, when establishing the microzonation maps, it is advised to work at a scale of 1:5,000. The final maps can easily be transferred later (and with engineering judgment) to the scale of the city plan.

Relation between Data Density and Scale

Resolution is the smallest distance that can be usefully distinguished on a paper map with a given scale. Generally, this distance is shown to be about 0.5 millimeters. For example, on a 1:10,000 scale map, the minimum distance that can be conveniently represented is about 5m.

The density data on paper maps are therefore limited by its scale, since any given area cannot be shown if it is smaller than the lines that should draw it. For example, a square less than 10m wide cannot be drawn on a 1:10,000 scale map.



Area delimited by four lines of thickness t　　*Smallest area that can be represented by four lines of thickness t*

Figure 1.1: Representation of areas on a map

1.2.5 Planning Strategy for Loss Reduction

Main Causes for Earthquake-related Losses

In general, risk reduction can be obtained by reducing the hazard, the vulnerability or the value at risk. Since the earthquake hazard cannot be reduced, one has to concentrate on vulnerability and value at risk.

Losses due do earthquake effects have three main causes:

1. **Earthquake hazard is not taken into account appropriately**. Typical examples are constructions in unsuitable areas, where earthquake effects are very probable, e.g. zones with high susceptibility for liquefaction, landslides, etc.

   <u>Countermeasures:</u> Appropriate land use management. Tool: Microzonation.

2. **Vulnerability of structures and infrastructure** does not take the earthquake hazard into account.

   <u>Countermeasures:</u>
   Earthquake-resistant design, taking modern building codes into account.
   - <u>New buildings</u> have to be designed according to building codes together with adequate construction and quality control. For new buildings, costs for a good earthquake-resistant design is negligible or very small (3-4% of construction costs), whereas upgrading of existing buildings can be very expensive.
   - <u>Existing important buildings</u> have to be upgraded to a sufficient degree.

3. **Intervention forces react too late or insufficiently after an event**.

   <u>Countermeasures:</u> Assuring that preparedness and capacity of intervention forces correspond to the regional risk.

Zoning and Microzonation as a Basis for Land Use Management

<u>General</u>

Small-scale seismic risk maps (Seismic Risk Map of Turkey) indicate the gross zones of expected earthquake effects based on seismological investigation and historical experience. Such maps provide general guidance for the application of building codes and for the evaluation of regional seismic risk.

The earthquake hazard is spatially distributed in relation to earthquake sources (faults) and local geological soil conditions. Mapping of variation in earthquake hazards at the municipal scale makes it possible to select relatively safer sites for the allocation of appropriate land resources. Urban development patterns can be oriented toward relatively safer zones. This minimizes losses.

Seismic microzonation maps at appropriate planning scale representing the distribution of relative ground shaking, liquefaction, landslide and rock fall potential provide the basis for effective earthquake safety planning at the scale of the municipality. The two principal considerations in earthquake loss reduction are siting and design.

Seismic microzonation maps provide a more detailed evaluation of potential earthquake effects, which can provide valuable guidance in urban planning and development. At the urban level, finer differentiation of seismic effects are more relevant and valuable since greater spatial variability in vulnerability levels are involved due to contrasting concentrations of distinct specializations in uses and buildings. Identification of areas of relative risk due to differentiated seismic hazards can be used to introduce earthquake safety as a factor in key development and siting decisions.

Knowledge of the variation of earthquake hazards at the microzonation level also is valuable to the structural designer and builder to enable them to anticipate problems related to amplification of shaking, liquefaction and landslides. Detailed site information for specific building design may still require site-specific investigation.

Planning Applications of Seismic Microzonation

Microzonation maps can be applied to development of general urban master development plans, which is also used in the management of development. In the case of formal land use zonation, the microzonation of earthquake hazards can be incorporated as a risk factor in the determination of permitted land uses. In the absence of a formal land use management system, microzonation can provide guidance in the following activities:

Comprehensive Planning and Zoning

In the preparation of urban development plans it is possible to evaluate the relative desirability of different options. Selection of sites for urban expansion and location of key facilities can be directed toward areas of relatively lower earthquake hazard. Areas of amplified ground shaking, liquefaction and landslide can be avoided. Safe siting reduces the likelihood of damage and may reduce the cost of safe construction.

Review of Development Applications

Seismic microzonation maps may be used to review development plans to assess specific known earthquake hazards associated with particular sites, where appropriate development may be limited to safer areas or additional specific investigations leading to an appropriately better design are required. In any case, the microzonation map can be used to inform the developer, property owners, and public at large of the particular earthquake hazards, which must be taken into account in design and construction.

Site-Specific Seismic Hazard Evaluations

Seismic microzonation maps do not provide detailed hazard parameters at the level of the specific building site. However, they do provide guidance to the municipal planning department on where site-specific investigations should be required.

Planning, Siting and Designing of Public Facilities and Utilities

At the urban scale, seismic microzonation maps provide useful guidance on the siting of public facilities and utilities. Public facilities such as schools and hospitals and police and fire stations should be located on the safest sites available. These types of facilities also tend to guide private development. It is, therefore, important that they guide development into relatively safer areas. Utilities are critical to the functioning of a municipality. Care must be taken in the siting of utility systems to avoid recognized areas of elevated earthquake hazard. Critical system components such as electrical substations and water pumping stations should avoid sites prone to liquefaction or landslides. Care should be taken in the design of network systems, which cross elevated hazard zones and special segments of known faults, a fact in many of the Anatolian towns.

Redevelopment and Seismic Retrofit

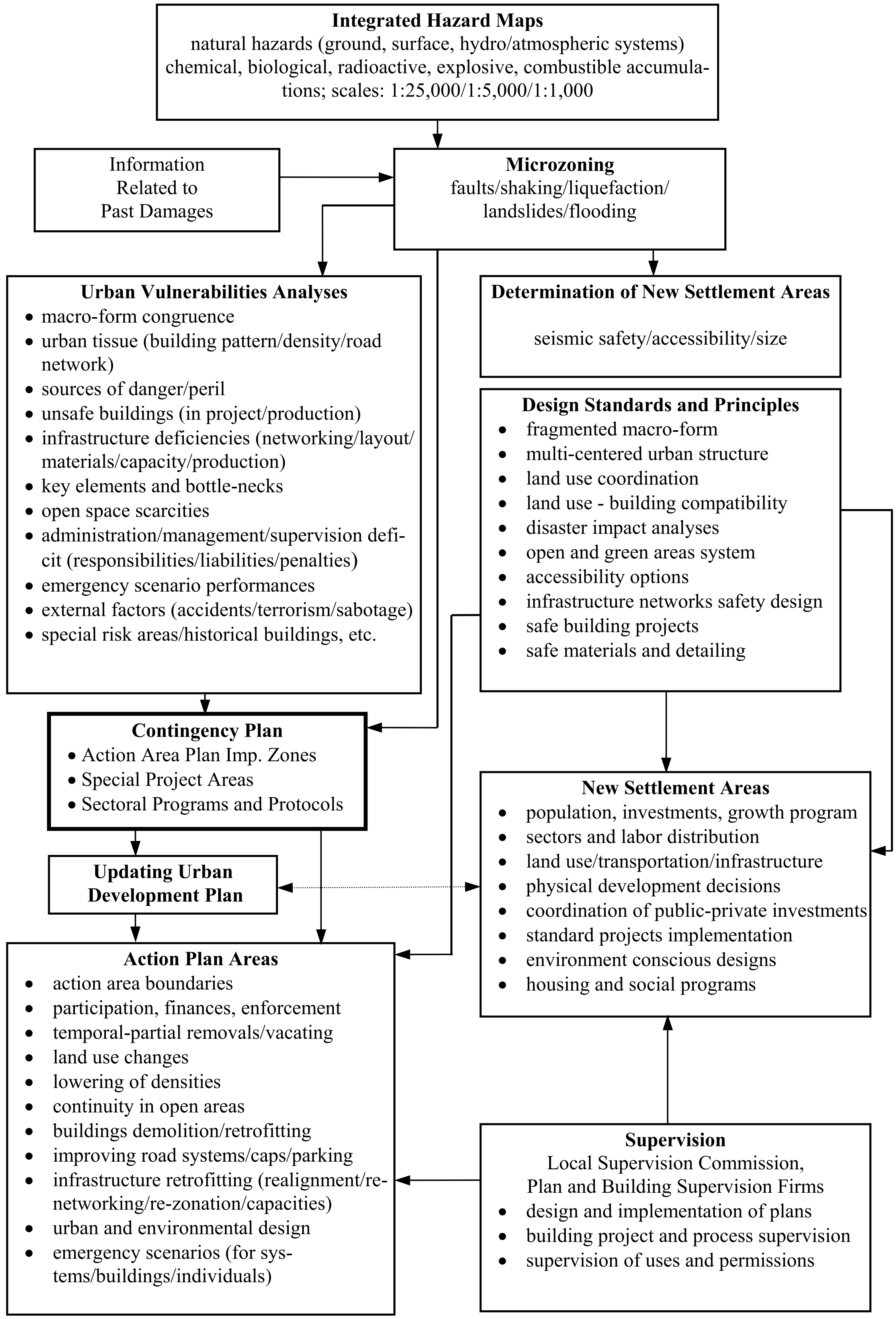
Seismic microzonation maps for a municipality will also indicate hazard zones for currently developed areas. In this case, the maps can be used to identify areas of critical exposure. For example, the location of a key facility such as a hospital or school in a zone of elevated hazard would suggest that it should be investigated for structural adequacy and possibly considered for upgrading or relocation. Many existing buildings are not adequately constructed to withstand expected earthquake forces. The seismic microzonation maps can help to set priorities for building upgrading and replacement. In the case of redevelopment, seismic microzonation can help to identify areas of highest risk and to identify areas suitable for relocation.

Emergency Management

Seismic microzonation provides a valuable tool for municipal emergency response planning. It provides the basis for the identification of the zones of the municipality most likely to experience serious damage in the event of an earthquake. This information can be used to prepare materials and equipment for emergency response and to develop training scenarios for emergency personnel (see Chapter 2.11.2).

Guidance for the Integrated Use of Financial and Other Tools

Seismic microzonation could also provide a basis for the market encouragement and discouragement of development. Explicit information on vulnerabilities will evidently generate appropriate behavior in the market. To reinforce such effects however, many city governments may choose to integrate their land-use guidance with financial tools and property rights. Thus for the imposition of differential property taxation, and insurance, and exercise of locational constraints in property rights and management, the microzonation maps and appropriate land use policies could provide the basic information for attaining safer conduct.


Integrated Hazard Maps
natural hazards (ground, surface, hydro/atmospheric systems) chemical, biological, radioactive, explosive, combustible accumulations; scales: 1:25,000/1:5,000/1:1,000
Information Related to Past Damages
Microzoning
faults/shaking/liquefaction/ landslides/flooding
Urban Vulnerabilities Analyses
• macro-form congruence
• urban tissue (building pattern/density/road network)
• sources of danger/peril
• unsafe buildings (in project/production)
• infrastructure deficiencies (networking/layout/ materials/capacity/production)
• key elements and bottle-necks
• open space scarcities
• administration/management/supervision deficit (responsibilities/liabilities/penalties)
• emergency scenario performances
• external factors (accidents/terrorism/sabotage)
• special risk areas/historical buildings, etc.
Determination of New Settlement Areas
seismic safety/accessibility/size
Design Standards and Principles
• fragmented macro-form
• multi-centered urban structure
• land use coordination
• land use - building compatibility
• disaster impact analyses
• open and green areas system
• accessibility options
• infrastructure networks safety design
• safe building projects
• safe materials and detailing
Contingency Plan
• Action Area Plan Imp. Zones
• Special Project Areas
• Sectoral Programs and Protocols
New Settlement Areas
• population, investments, growth program
• sectors and labor distribution
• land use/transportation/infrastructure
• physical development decisions
• coordination of public-private investments
• standard projects implementation
• environment conscious designs
• housing and social programs
Updating Urban Development Plan
Action Plan Areas
• action area boundaries
• participation, finances, enforcement
• temporal-partial removals/vacating
• land use changes
• lowering of densities
• continuity in open areas
• buildings demolition/retrofitting
• improving road systems/caps/parking
• infrastructure retrofitting (realignment/re-networking/re-zonation/capacities)
• urban and environmental design
• emergency scenarios (for systems/buildings/individuals)
Supervision
Local Supervision Commission, Plan and Building Supervision Firms
• design and implementation of plans
• building project and process supervision
• supervision of uses and permissions

Microzonation as Basis for Setting Priorities in Reducing Vulnerability of Critical Infrastructure

General:

Microzonation maps directed to land use management can be used to reduce earthquake risk by setting priorities in areas where reducing the vulnerability is most effective.

In a pragmatic way, this can be done by the following steps (details are given in Chapter 2):

1. Identifying elements of a critical infrastructure system (e.g. water system, energy distribution system, transportation system) and defining their individual elements (e.g. control center distribution lines, etc.). Assessing the importance of each element in three importance classes ("very important," "important," "less important"), to ensure the functional efficiency of the system.
2. Overlapping the infrastructure network on the individual hazard maps.
3. Experience-based assessment of overall vulnerability of each element of the importance classes "very important" and "important."
4. Reduction of the vulnerability according to the priority defined by the local hazard and the vulnerability of each element. Technical details are given in Chapter 2. Administrative details are given in Chapter 3.

Microzonation as Basis for Assessment of the Capacity and the Structure of Intervention Forces

The needed capacity of intervention forces can be assessed on the basis of microzonation maps. This is done by assessing the damage grade based on the vulnerability of uniform construction type zones and the critical infrastructure, using the definitions in the EMS-98 scale.

Technical details are given in Chapter 2. Administrative details are given in Chapter 3.

1.2.6 Characterization of the Hazard Environment, Principal Effects to be taken into Account in Turkey

1.2.6.1 Evaluation of Earthquake Hazard for Microzonation

Need for Earthquake Hazard for Microzonation

The earthquake zone map for Turkey that was renewed in 1997 is a seismic **macrozonation** map based on regional characterization of the earthquake hazard with respect to five earthquake zones. The boundaries of these five zones were deduced from a probabilistic seismic hazard assessment of peak ground accelerations. The scale of this study and the related map is 1:1,800,000. However, this macrozonation map does not specify any quantitative earthquake hazard parameters for any zone. In the Turkish Earthquake Code, an effective acceleration parameter was recommended for each zone to be adopted in the engineering seismic design of buildings. This parameter is not an average or median peak acceleration of the region, but a parameter selected for design purposes.

Thus the available earthquake zone map of Turkey can not be used for microzonation purposes because:

(a) the accuracy of the map is too low for microzonation studies;
(b) it does not have appropriate quantitative earthquake hazard parameters attached to the different zones, which could be used as input for microzonation purposes.

Therefore it is essential to conduct a regional seismic hazard study based on detailed regional geological investigations preferably with an accuracy of 1:25,000 map scale coupled with seismological studies. It is preferable that these earthquake hazard maps should be defined with respect to spectral accelerations for competent site conditions.

The other output from the earthquake hazard study should be acceleration time history records based on the probabilistic procedure adopted for the earthquake hazard assessment. These time history records would be used for site response analysis.

Technical details are given in Chapter 2 as well as in the Reference Information, State-of-the-Art, Chapter 4.

1.2.6.2 Ground Shaking Intensity

Importance of Shaking

Ground shaking is a term used to describe the vibration of the ground during an earthquake. Ground shaking is caused by body and surface seismic waves. As a generalization, the severity of ground shaking increases as magnitude increases and decreases as distance from the causative fault increases.

Although the physics of seismic waves is complex, ground shaking can be explained in terms of body waves:

- "Compression" or P waves
- "Shear" or S waves and
- "Surface waves", Rayleigh and Love waves.

P waves propagate through the earth with a speed of about 2,000 to 7,000 m/s and are the first waves to cause vibration of a building. S waves arrive next and cause a structure to vibrate horizontally. These are the most damaging waves, because buildings are more easily damaged from horizontal motion than from vertical motion, since the usual structural design concentrates on vertical loads. The P and S waves mainly cause high-frequency vibrations, whereas Rayleigh and Love waves, which arrive last, mainly cause low-frequency vibrations. Body and surface waves cause the ground, and consequently a building, to vibrate in a complex manner.

The objective of earthquake-resistant design is to construct a building in such a way that it can withstand the ground shaking caused by body and surface waves.

The different wave types travel from the earthquake source to the surface causing horizontal and vertical movements of the ground surface. These movements can be quantified by measurements of strong-motion seismographs, resulting in accelerograms showing the course of the ground acceleration during an earthquake.

Accelerograms

Accelerograms can be used to evaluate the forces on buildings and other structures. It is important to consider not only the acceleration amplitudes but also the frequency content of the motion, which has an influence on the structural response. A typical acceleration time history, with corresponding Fourier spectrum (representing the frequency content of the time history), is shown in Figure 1.2.

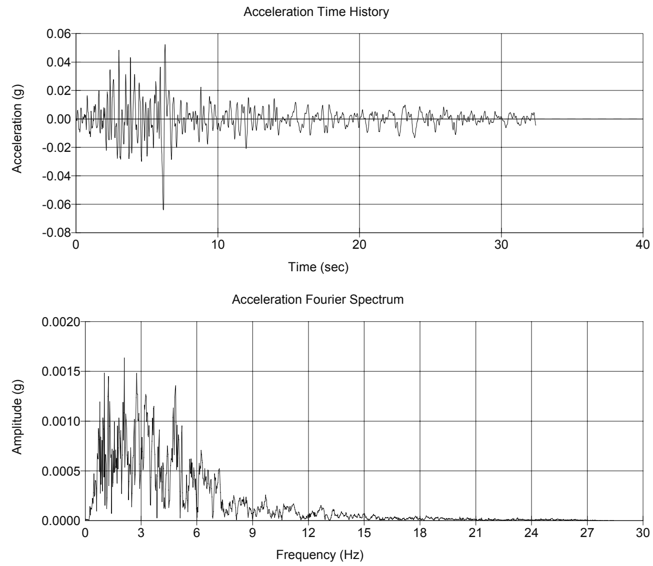


Figure 1.2: Acceleration time history and corresponding Fourier Spectrum for a given earthquake event

Response Spectrum

The response spectrum shows the peak responses of elastic single degree of freedom systems (SDOF) with a fixed damping ratio for a given earthquake acceleration time history plotted in function of the fundamental frequencies of the SDOF. So the impact of the considered acceleration time history on structures can be illustrated by means of a response spectrum. Figure 1.3 shows the acceleration response spectrum corresponding to the time history in Figure 1.2.

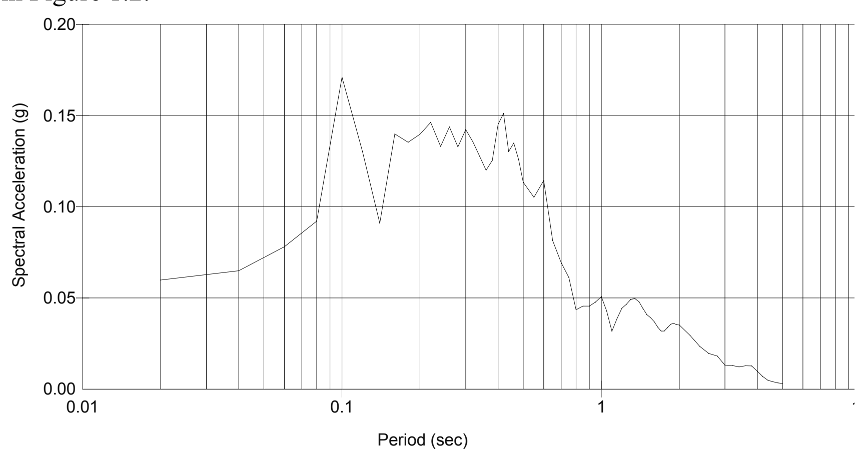


Figure 1.3: Sample Response Spectrum

Design Spectra

Design spectra are used in the design of structures, and can be found in national Building Codes. They are derived from a larger sample of individual response spectra from earthquakes with different magnitudes, frequency content and duration, which are representative for the geotechnical site conditions of the region or country. In general, they are defined at surface, depending on specific soil conditions (e.g. rock) for 5% damping.

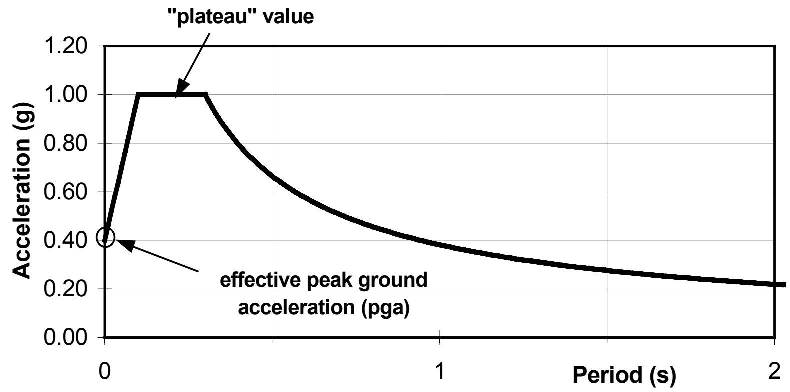


Figure 1.4: Example of Design Spectrum from Turkish Building Code, Zone 1, Rock Conditions, 5% damping

Influence of Local Geological and Topographical Conditions

The amplitude and duration of ground shaking at a specific site depends on different factors:

- Energy release of the earthquake event, depending on rupture size and type
- Directivity of the energy release, depending on the orientation of the rupture fault
- Distance from the site to the earthquake source
- Geological conditions between the earthquake source and the site
- Local soil and topographical conditions.

Local geological and soil conditions at a specific site can increase or decrease the mean shaking intensity, as well as the duration of the shaking.

Typical Examples of Damage in Turkey Caused by Ground Shaking

Figure 1.5: Variation of damage in Gölcük (Kocaeli Earthquake 1999). Totally collapsed building and buildings with moderate damage possibly as result of different construction layouts or site factors

Figure 1.6: Damage in Adapazari (Kocaeli Earthquake 1999). Collapse of soft story

1.2.6.3 Liquefaction and Settlements

General Remarks

Liquefaction is a process by which water-saturated sediment temporarily loses strength and stiffness and acts as a fluid. Liquefaction takes place when loosely packed, waterlogged sediments at or near the ground surface lose their strength in response to strong ground shaking. This reduction of strength is due to the fact that during dynamic excitation, pore water pressures in the sediment tend to increase, if above conditions are fulfilled. The increase of pore water pressures cause the effective stress to decrease, which in turn affects the soil strength and stiffness.

Importance of Liquefaction and Settlements

The reduction of soil strength and stiffness due to the occurrence of excess pore water pressures caused by earthquake excitations can result in excessive settlements, tilting and structural damage. Liquefaction occurring beneath buildings and other structures can cause major damage during earthquakes. Stability can be endangered by the reduced shear strength, even in gentle slopes.

The most commonly affected structures are buildings, bridge supports and lifelines. The deformations and differential deformations induced by the loss of soil strength and stiffness can often not be withstood by these structures. But even without a real structural failure, excessive settlements or tilting constitutes irreparable damage in the majority of cases.

Characteristics of Local Soil and Groundwater Conditions Influencing Liquefaction Potential

The principal conditions for liquefaction or excessive settlements are:

- The soil consists of a loose granular material
- High water table near the surface, resulting in saturated soil conditions.

Only under the above conditions can excess pore water pressures develop during an earthquake, to reduce considerably or lead eventually to a total loss of the soil strength and stiffness. The knowledge of the detailed soil conditions at a specific site is therefore essential in order to be able to predict the liquefaction susceptibility.

Principal investigations for the assessment of the liquefaction potential are given in Chapter 2 of this manual.

Typical example of Damage in Turkey caused by Liquefaction

Figure 1.7: Manifestations of liquefaction in Adapazari (Kocaeli Earthquake 1999)

1.2.6.4 Landslides, Rock Fall

Importance of Landslides and Rock Fall

Slope failures and rock falls during earthquakes have claimed a great number of casualties and have been a major cause of damage to structures and facilities constructed on or in the vicinity of the slopes.

These failures can range in volume from a fraction of a cubic meter to some hundred thousand cubic meters. The displacements can range from a few meters to some hundred meters or even more.

There can be various effects of these failures:

- Damage to buildings, bridges, dams and other structures by sliding or falling earth masses
- Blocking of roads and railroads
- Damage to underground structures
- Local disruption of infrastructure systems such as water mains, sewers, gas or power lines.

Characteristics of Local Soil and Topographical Conditions Influencing the Hazard for Slope Instability

Two basic factors lead to permanent down-slope motions:

- Inertial forces, which will cease once shaking stops
- Loss of strength, which may exist also after shaking ceases.

The loss of strength may have different causes, such as excess pore water pressures built up during the dynamic excitation, or initiation of sliding in shear planes. Motions due to loss of strength caused by excess pore water pressures may continue after the excitation, due to the fact that it takes time for the excess pore water pressures to decrease again. The motion process may continue until the safety factor reaches unity.

The stability of a slope depends on its geometry and its soil conditions, as well as on the hydrostatic conditions.

The knowledge of the soil conditions as well as the hydrologic situation is therefore a prerequisite in order to be able to predict the behavior of the slope.

Typical example of Damage in Turkey caused by Landslides

Figure 1.8: Slope failure along the Istanbul-Bolu highway (Duzce Earthquake 1999)

1.2.6.5 Earthquake-related Flooding

Importance of Earthquake-related Flooding (Inundation, Seiches etc.)

The flooding effects related to earthquake events are tsunamis, seiches and lateral spreading along the coastline.

Tsunamis are waves induced by submarine earthquakes. They are characterized by wavelengths of up to 100km, with periods of up to one hour. Tsunamis behave as shallow-water waves, which implies that their velocity increases with the water depth. Near the coastline, the water depth and therefore the speed diminish. In exchange, the wave height increases, due to the constant energy flux of the wave. The height of these waves can reach tens of meters and cause enormous damage to the coastline.

Seiches are standing waves in closed or semi-enclosed basins (lakes). Seiches can be earthquake-triggered by different causes: Rupture of the basin ground, landslides, shaking. Although the height of these waves is considerably smaller than for tsunamis (about 1-2m), the potential damage should not be undervalued:

- Flooding and damage to buildings near the shoreline
- Damage to dams, especially overflowing of earth dams
- Damage due to trees tipped over (resulting in damage to structures or blocking of roads and railroads).

Flooding Due to Earthquake Induced Upstream Dam-Break

If a dam of a water reservoir upstream breaks, flooding can damage large areas downstream. This hazard and the affected area had to be evaluated during the design phase of the dam. These data can be obtained from the dam owner or the safety related agency and should also be incorporated in the microzonation maps.

Influence of Bathymetric and Local Topographical Conditions

Only the knowledge of the bathymetric conditions, as well as the topography of the coastline, make it possible to make an estimation of the possible damage due to tsunamis, seiches or lateral spreading.

Typical example of Damage in Turkey due to Earthquake-related Flooding

Figure 1.9: Sliding and flooding along the Gölcük coast (Kocaeli Earthquake 1999)

1.2.6.6 Surface Faulting and Tectonic Deformation

Importance of Surface Faulting and Tectonic Deformations

During very strong earthquakes, faults often extend to the surface. The location of the fault break at the surface can differ from earthquake to earthquake. Therefore, a precise prediction of zones with high potential for surface faulting may not be possible.

Damage due to surface faulting and tectonic deformation occurs in a restricted area, where the active fault causing the earthquake event crosses the surface.

Depending on the rupture type of the fault, different effects can be observed, for example:

- Vertical displacements
- Lateral offsets.

Structures mostly cannot withstand these high deformations. Most affected by surface faulting and deformations are linear structures, such as pipelines, streets, railroads or irrigation channels.

Typical example of Damage in Turkey due to Surface Faulting

Figure 1.10: Fault rupture with lateral displacements of around 4m (Kocaeli Earthquake 1999)

2. Guidelines and Recommendations for the Commissioned Enterprises

2.1 List of Symbols and other Terms

Symbols and terms	Definition
EMS-98	European Macroseismic Scale 1998
CPT	Cone Penetration Test
CPTU	Cone Penetration Test, including the measurement of pore water pressure
SCPT	Seismic Cone Penetration Test
SASW	Spectral Analysis of Surface Waves
SPT	Standard Penetration Test
v_s	shear wave velocity
M_w	Moment magnitude
S	Plateau value of acceleration response spectrum at the ground surface, see Figure 1.4.
g	Gravity acceleration
A, B, C	Defined microzones
F_s	Factor of safety
q_c	Cone resistance (CPT test)
f_s	Sleeve friction (CPT test)
R_f	Friction ratio (CPT test, $R_f = f_s/q_c$)
u_2	pore water pressure (CPT test)
pga, PGA	Horizontal Peak Ground Acceleration
Competent soil layer (competent site conditions)	The stiffness of the competent soil layer corresponds to B/C boundary of the NEHRP site classification with shear wave velocities assumed to be around 760 m/s.
Earthquake Scenario	An earthquake scenario defines a specific earthquake. The earthquake can be deducted from a past event or by a probabilistic seismic hazard assessment. If the earthquake scenario is described by intensities, a crude damage evaluation is particularly easy by using the vulnerability classes and damage grades of the EMS scale (chapter 2.11.4).
Characteristic earthquake	Earthquake derived by deaggregation of the regional hazard calculation (recommended method). If no deaggregation results are available, M_w is taken as 6.5.

2.2 Scope and General Methodology

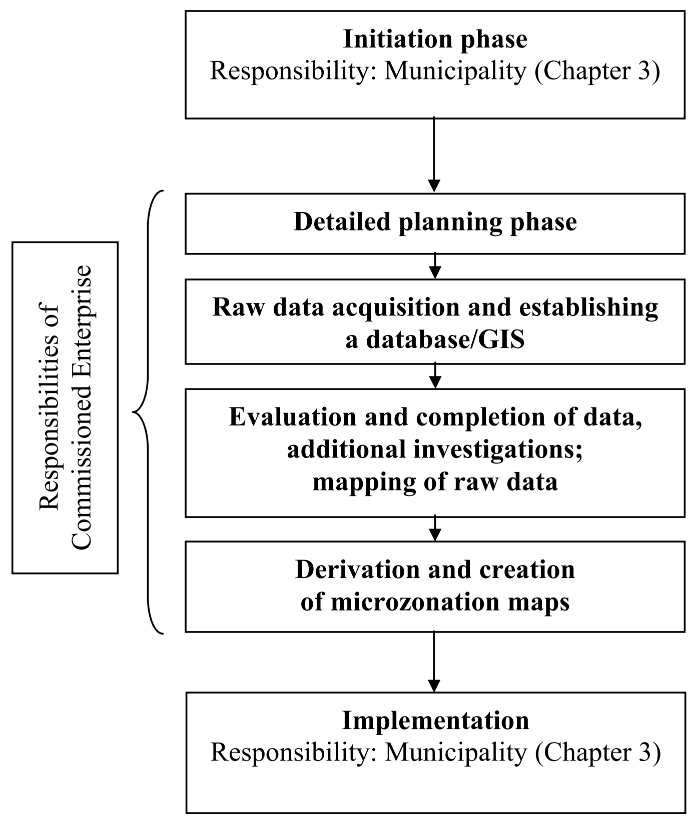
Scope

This chapter defines:

- The detailed microzonation procedure including milestones
- Minimum requirements for data acquisition and evaluation
- Decision support documents and checklists

General method

The following phases should be followed when performing a microzonation study:



The following chapters give recommendations and technical details for the commissioned enterprises to perform the microzonation study.

Responsibilities of the Municipality

The responsibilities of the municipalities are defined in Chapter 3 of the manual.

Professional Requirements for the Commissioned Enterprise

The commissioned enterprises should prove by appropriate references that their leading staff members have sufficient technical knowledge and <u>experience</u> to conduct a microzonation study successfully.

Professional Requirements for the Project Manager

The project manager should be an experienced geotechnical engineer or engineering geologist with broad knowledge in earthquake seismology and soil dynamics.

2.3 Responsibilities of the Commissioned Enterprises

The responsibilities of the commissioned enterprises are described below for the different phases.

The enterprise commissioned for the microzonation study should interact frequently with the relevant municipal technical and administrative staff, throughout the whole study, from planning to final mapping.

Detailed planning phase

Detailed work plan and timetable for procurement of services (see Chapter 2.4)

Experience shows that in the course of data acquisition, unforeseen circumstances can appear, leading to modifications and additional investigations. It is therefore advised to have some flexibility in the work plan and the timetable.

Raw data acquisition and establishing a database/GIS

Assessment of regional hazard, if not delivered by the responsible agency (see Chapter 2.5)

Obtaining basic topographic information (topographic map scale 1:5,000, digital format)

Establishing database templates/GIS (see Chapter 2.6)

Collection of already existing geotechnical, geological and geophysical data within project area (see Chapter 2.6)

Database development for mapping of the raw data.

Evaluation and completion of data, additional investigations

Review of seismological, geotechnical and geological data for quality and completeness.

If needed, the data should be corrected appropriately and completed with additional investigations. The representativeness and the geographic accuracy of these data will determine the reliability of the microzonation study.

Mapping of raw data

Mapping of **raw data** with corresponding location and attributes as layers of the topographical map (see Chapter 2.7.8), including regional hazard map on competent site conditions.

Derivation and mapping of microzonation maps

Derivation of the input data for microzonation maps with the evaluation criteria described in Chapter 2.8.

Mapping of the following **microzonation maps**:
- Surface faulting map
- Ground shaking maps
- Liquefaction susceptibility map
- Landslide and rock fall hazard map
- Earthquake-related flooding hazard map

Drafting of zone-specific building recommendations (See Chapter 2.9).

Final technical report (format for submissions see Chapter 2.10).

2.4 Initiation Phase and Detailed Planning Phase

Steps

The following steps should be followed at the beginning of the project by the enterprises in charge of the microzonation:

Initiation phase and detailed planning phase

Define:
- Project manager
- Detailed work plan
- Milestones
- Information flow

Responsibilities and Recommendations

- The enterprise commissioned for the microzonation is responsible for the detailed planning phase described above.
- Work plan and milestones should be approved by the Municipal Steering Committee (Chapter 3).

2.5 Assessment of Regional Hazard

Needed Results

The assessment of regional hazard for microzonation purposes should be based on a Probabilistic Seismic Hazard Assessment (PSHA). PSHA provides a framework in which uncertainties can be identified, quantified, and combined in a rational manner to provide a more complete picture of the seismic hazard.

The result required for each grid point is the probabilistic earthquake acceleration response spectrum for 5% damping valid for competent site conditions for the period range of 0.1 to 10s, for the return period of 100 years. This return period does not correspond to the return period of the Turkish Building Code (475 years). However, this lower return period improves the validity range of the simplified methods to assess the shaking level. Based on the accuracy of the basic data and on the size of the grid, this return period is appropriate to assess the relative shaking level.

Based on this response spectrum at the competent soil layer, at least two independent sets of time histories should be defined at each grid point for site amplification studies. These time histories can be derived either by modification of recorded earthquakes or by simulated earthquakes. In the latter case, non-stationary simulation is preferred as this type of simulation is much closer to recorded earthquakes than stationary simulation. The program TARSCTHS can be used for this purpose (see references).

Professional Requirements

PSHA requires experience in processing and evaluating earthquake catalogues, attenuation laws and interpretation of results. The commissioned enterprise should prove that it has this experience; otherwise at least the part including the PSHA should be outsourced to a competent consultant.

The hazard calculation should take into account the particular conditions of the area, and often no simple standard procedures can be applied. It is therefore strongly recommended that experts in probabilistic seismic hazard calculations perform this part. The overall accuracy of the microzonation depends mainly on the hazard evaluation and the quality of the geotechnical data.

Basic Steps

Basic steps when performing a PSHA are as following:

1. The most important and fundamental input to a model of earthquake hazard is a collection of earthquake events that represent the temporal and spatial distribution of seismic activity in the region. The available catalogues should be checked carefully for uncertainties and completeness, magnitudes should be unified and duplicate entries should be eliminated. Uniformity in magnitude for the whole earthquake catalogue must be achieved. The moment magnitude M_w is the preferred quantity for measuring the size of an earthquake. Other magnitude scales suffer from "magnitude saturation” with increasing earthquake size.
   It is recommended that preferably the catalogues provided by Kandilli Observatory be used, or equivalent catalogues be defined by the relevant authority.

2. Identification and characterization of earthquake sources, line or area sources, capable of producing significant ground motion at the site (seismic source model) should be carried out. The source characterization includes the definition of each source's geometry,

earthquake potential (frequency distribution and maximum magnitude) and the probability distribution of the potential rupture location within a seismic zone. In most cases, uniform probability distributions are assigned to each source zone, implying that the earthquakes are equally likely to occur at any point in a source zone. These distributions are then combined with the source geometry to obtain the corresponding probability distributions of a source to distance setup.

3. The temporal distribution of earthquake occurrence must be evaluated for each zone. A recurrence relationship, which specifies the average rate at which an earthquake of a certain size will be exceeded, is used to characterize the seismicity of each zone.

   Several computer programs exist to facilitate this task (e.g. Wizmap II [Musson R.M.W., British Geological Survey, Edinburgh, 2001].

4. Predictive attenuation relationships must be selected to determine the ground motion produced at the site by any earthquake in any possible location in each zone (see also next subtitle).

5. Uncertainties in earthquake location, earthquake size and attenuation laws are combined to obtain the probability that a particular ground motion will be exceeded during a particular time period.

Attenuation relationships

The limited strong motion data in Turkey and also in the Eastern Mediterranean region, and ambiguities on the station site descriptions, do not allow for the development of reliable region and site-specific ground motion attenuation relationships. Owing to the geological and geo-tectonic similarity of Anatolia to the California and also on the basis of favorable predictive comparisons, the attenuation relationships currently being used for the assessment of earthquake hazard for the western United States can be used for applications in Turkey.

The recommended relationship for the use in Turkey based on comparisons with Turkish earthquake data is the Boore, Joyner and Fumal (1997) relationship.

Computer Programs

Several computer programs are available to perform the PSHA calculations. Among the recommended programs are:

- SEISRISK III (Bender B., and Perkins, D.M. 1987- SEISRISK III. A Computer Program for Seismic Hazard Estimation US Geological Survey, Bulletin 1772.)
- EZ-FRISK (Risk Engineering, Inc., Colorado, USA, 2000)
- FRISK88 (Risk Engineering, Inc., Colorado, USA, 1988)
- EQRISK (R. K. McGuire, U. S. Geological Survey, Denver, Colorado 1976, Modified by Risk Engineering, Inc., Golden, Colorado 1980)
- TARSCTHS ("Target Acceleration Response Spectra Compatible Time Histories," Engineering Seismology Laboratory, State University of New York at Buffalo)

Further details on the assessment of the regional hazard can be found in the Reference Information, State-of-the-Art, Chapter 4.

2.6 Raw Data Acquisition and Establishing a Database/GIS

2.6.1 Basic Steps

Basic data needed

The following basic data groups are needed:

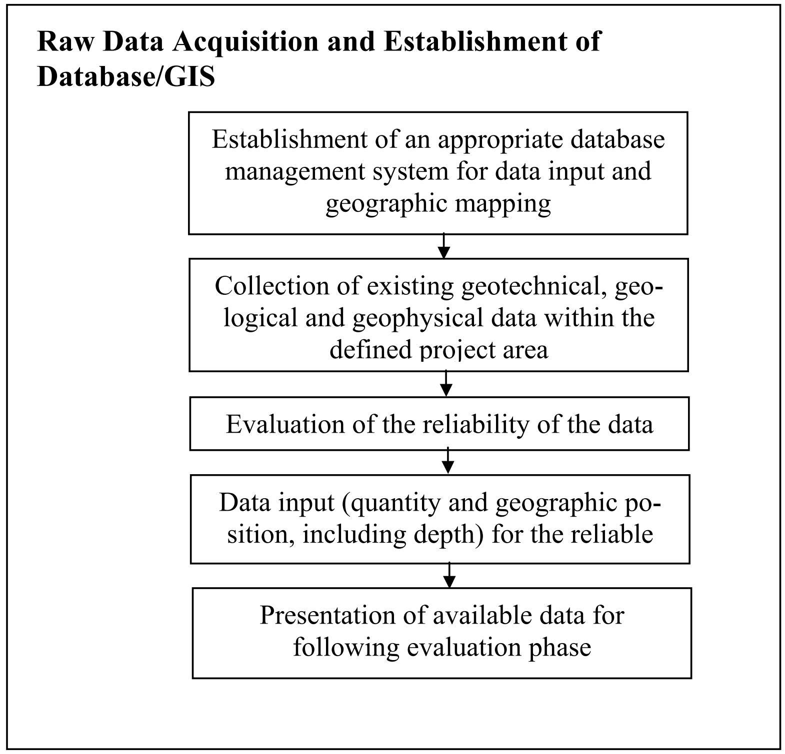
Data group	*To be provided by*
Topographical data (Digital format)	Municipality
Regional earthquake hazard, associated with 100-year average return period for the region.	To be evaluated by commissioned enterprise, if not provided by GDDA (preferred solution)
Neotectonic data [1)]	To be evaluated by literature review, if not provided by GDDA (preferred solution).
Basin Topography	To be assessed by commissioned enterprise, if not provided by GDDA (preferred solution)
Geotechnical/Geological/ Geophysical data	To be acquired by commissioned enterprise.

Comments

[1)] Neotectonics is the study of geologically recent motions of the earth's crust, particularly those produced by earthquakes, with an aim toward understanding the physics of earthquake recurrence, the growth of mountains, and the seismic hazard embodied in these processes.

Steps

The following steps should be followed when acquiring the available data:



2.6.2 Basic Geotechnical and Geophysical Data

Principles

The collection of the geotechnical and geophysical basic data in the defined project area should include all existing data, after a plausibility check to exclude evident errors.

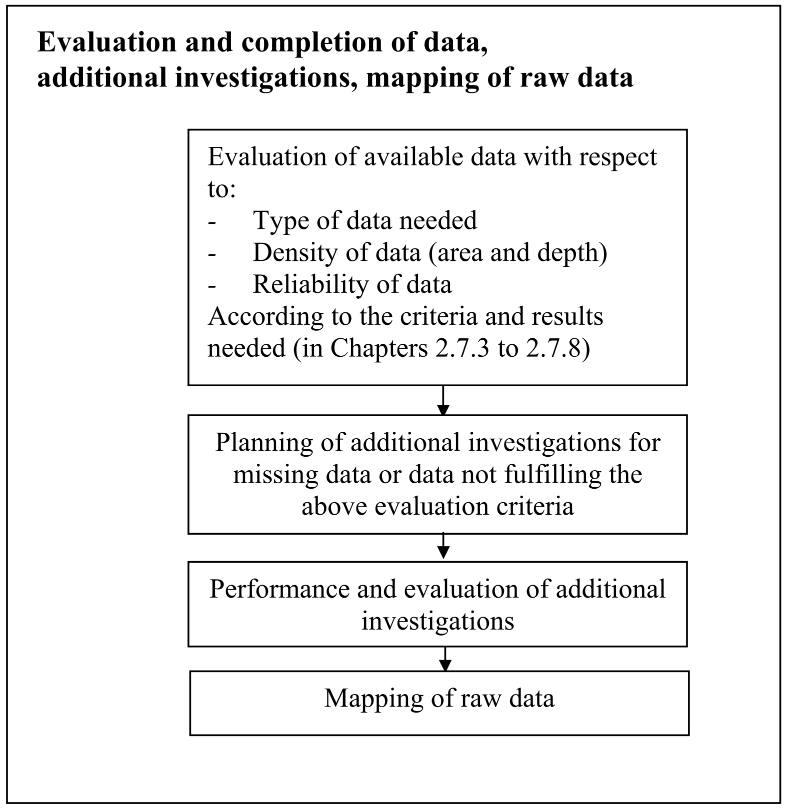
In order to achieve the basic data set needed to evaluate ground shaking, liquefaction susceptibility, and landslide hazard, additional investigations are most likely to be necessary.

2.7 Evaluation and Completion of Data, Additional Investigations, Mapping of Raw Data

2.7.1 Basic Steps

Steps

The following steps should be followed when evaluating the available data:



2.7.2 General Recommendations for Additional Investigations

Principles, grid size

The reliability of the final microzonation maps depends on the assessment of representative soil layers. Several methods can be used to get this information.

The most economic procedure is to collect the data in a grid format and to densify this initial grid where needed.

Whereas data to assess shaking amplification are needed for every grid point, data to assess liquefaction or slope stability are only needed in areas where these effects are expected (criteria see Chapter 2.8.4 and 2.8.5).

The required grid of data points depends on the homogeneity of the geological and topographical conditions. The denser the grid, the higher is the resulting accuracy, but the amount of work needed will increase considerably.

The following <u>grid sizes</u> are recommended:
- **For homogeneous areas (in respect of geology and topography), a grid distance of 500m is acceptable.**
- **For non-homogeneous conditions, a denser, site-specific grid may be chosen, with respect to the variability of the conditions.**

Additional investigations

Additional investigations for a specific grid position are required in the following cases:
- No basic data within the defined position
- Reliability of data is questionable and/or is not consistent with the surrounding data within the grid or with the neighboring grids.

2.7.3 Basic Geotechnical and Geophysical Data

Recommended methods to obtain input data of soil profile at grid point

The geotechnical and geophysical basic data, which are essential for the microzonation, are shown below, together with the corresponding recommended evaluation methods:

Essential Input Data	***Recommended Methods***	***Chapters***
Topography	- Digital topographic basic information (topographic map at scale 1:5,000 may be obtained from finer scaled maps)	-
Groundwater table	- Boreholes and/or geoelectric soundings, CPTU [1)] (including information on seasonal influences)	2.12.1 2.12.8
Geotechnical units	- Detailed surface geology maps - Geological/geotechnical in-situ data (Borings, SPT, CPT, CPTU) [2)] - Geophysical methods (SASW, Cross-hole, In-hole seismic wave velocity measurements, Micro-tremors, CPT Seismic cone, etc.) [3)]	- 2.12.1 2.12.2 2.12.3 2.12.4 2.12.5 2.12.6 2.12.7
Bedrock or Competent site conditions ($v_s \geq 700$ m/s)	- Borings & Geophysical methods [4)]	-
Delineation of Basin structures	- Deep seismic surveys or microtremor array measurements [5)]	2.12.7
Basic geotechnical and geophysical properties of the different geotechnical units: • Strength parameters (shear strength parameters in areas with potential stability problems) • Shear wave velocity	- Laboratory tests[6)] - Correlations with SPT or CPT/CPTU tests [7)] - Geophysical methods [8)] (SASW, Cross-hole, In-hole, Micro-tremors, Seismic Cone etc.)	- 2.12.1 2.12.2 2.12.3 2.12.4 2.12.5 2.12.6 2.12.7

Comments

[1] All methods recommended. Selection depends on economic criteria.

[2] Borings give the best overview for layering, but the drilling is expensive. CPT gives less accurate results and can only be used in soft soils, but is less expensive. SPT is recommended since it is a widely used and cost-effective method. CPTU tests are recommended for assessing the stratification of the ground. With the additional measurement of pore pressures, essentially undrained layers (silts, clays) can be easily distinguished from essentially drained layers (sands, gravels). Nevertheless, a minimum number of boreholes (at least one per area with similar underground conditions, derived from the existing database, preferably one borehole or one in-situ test for each grid) is always needed to correlate results of SPT/CPT or geophysical investigations with geotechnical units. The boring depth shall be around 30m, with some deeper boreholes to understand the thickness of the soil deposit.

[3] Provides best shear wave profile, but layer identification is less detailed than from boreholes. Medium price range.

A minimum number of boreholes (at least one per area with similar underground conditions, derived from the existing database, preferably one borehole or one in-situ test for each grid) is always needed to correlate results of geophysical investigations with geotechnical units.

[4] Borings are only cost-effective up to a maximum depth of 30m. For deeper bedrock, geophysical methods are recommended.

[5] Reliable results are obtained only if performed by experienced and highly specialized personnel.

[6] For shaking amplification: cyclic tests are expensive, therefore only recommended in critical situations. Otherwise correlations for the non-linear behavior of geotechnical units are, in general, sufficient. Soil degradation curves should be used, preferably from regionally developed relationships.

For liquefaction susceptibility: cyclic lab tests are not compulsory, field data are more reliable. Sieve analysis (fines content) should be determined.

For landslide hazard: laboratory strength tests are expensive, therefore only recommended in critical situations. Correlations with geotechnical units are generally sufficient.

[7] For investigations of shaking amplification: correlation for v_s only in case no shear wave measurements are available.

For liquefaction susceptibility: SPT gives best correlation with liquefaction susceptibility, but only at specific depths.
CPTU test correlations are somewhat less accurate, but give results over the whole depth range.

For landslide hazard: correlations with shear strength parameters.

[8] Best results for shear wave profile

2.7.4 Raw Data for the Preparation of the Surface Faulting Map

A geological map of the investigated area and its surroundings should be provided, indicating faults with documented activity, potentially active faults and faults without indication for activity.

If earthquakes surface faulting was observed in the past, the tracks of the observed faults should be mapped, based on the available documents.

2.7.5 Raw Data for the Preparation of the Ground Shaking Map

General comments

The **ground-shaking map** presents the calculated shaking level (spectral values) at grid points and selected other profiles.

The following input data are needed to get the spectral values at the surface:

- Earthquake hazard (several time histories) at competent site conditions, calculated for a return period of 100 years.
- Shear wave velocity profile (either measured directly or by correlation from basic geotechnical data)
- Material behavior under cyclic loading (by correlation from regional geotechnical data if available)

Several techniques are available to calculate the shaking at the surface. For microzonation purposes, one-dimensional analysis is generally acceptable (Chapter 2.12.9) for sites where 2D/3D effects are not dominant and not expected.

Particular attention should be taken when using 1D-equivalent linear analysis for very deep profiles (e.g. bedrock depth > 500m). In such cases, it is recommended that the frequency dependence of both shear modulus and damping be taken into account, in relation with the strain spectrum and the degradation curves.

Input data: hazard on competent site conditions at grid points

If the earthquake hazard at competent site conditions (time history at grid points) is not available, it should be determined by the commissioned enterprise according to Chapter 2.5.

However, it is strongly recommended that GDDA provide the local hazard at competent site conditions, in order to achieve homogeneous results over the different project areas.

Recommended methods to obtain input data of soil profile at grid point

Essential Input data	***Recommended Methods***	***Chapter***
Depth of engineering Bed-rock or Competent soil layer ($v_s \geq 700$ m/s)	- Borings & Geophysical methods [1]	-
Groundwater table	- Boreholes and/or geoelectric soundings, CPTU [2]	2.12.1 2.12.8
Shear wave profile (one of these methods)	- Correlations with geotechnical properties [3] - Cross-hole method [4] - Up, Down and In-hole methods [5] - Seismic CPT [5] - SASW [6] - Array measurements [7]	- 2.12.3 2.12.4 2.12.1 2.12.5 2.12.7
Material behavior under cyclic loading	- Standard modulus reduction curves and damping curves [8]	2.12.10
Predominant period	- Microtremor measurements [9]	2.12.6
Basic geotechnical properties of the different geotechnical units.	- Laboratory tests [10] - Correlations with SPT or CPT tests [11]	- 2.12.1 2.12.2
Soil Classification [12]: - Turkish Building Code - NEHRP Average shear wave velocity $v_{s,30}$	-	-

Comments

General comment: the methods described above can be combined for economic reasons. But it should be assured, that at each grid point, the required data are sufficiently representative and complete. For instance, in homogeneous conditions, some few SASW tests could be combined with correlations of geotechnical units.

[1] Borings are only cost-effective up to a maximum depth of 30m. For deeper bedrock, geophysical methods are instead recommended. An evaluation of the most suitable method is necessary, given local conditions.

[2] All methods recommended. Selection of the method depends on economic criteria.

[3] The use of correlations with geotechnical properties needs experience. The results are sufficiently accurate, but less accurate than those obtained by geophysical methods.

[4] The cross-hole method test gives very reliable results, but is expensive, since at least two or preferably three boreholes are needed. Recommended

in critical areas.

5) Are cheaper than cross-hole testing, since only one borehole is needed. But the results are less accurate. Seismic CPT also gives acceptable results, and no borehole is needed.

6) Gives sufficiently accurate results, but extensive experience is needed to interpret the measurements, lies in a low to medium price range. <u>In general it is the recommended method.</u>

7) Gives sufficiently accurate results, but experience is needed to interpret the measurements. Low to medium costs.

8) The use of standard modulus reduction and damping curves is acceptable for most soils. Laboratory tests are possible, but very expensive.

9) Strongly recommended to adjust the soil model (calculation has to be done with low strain earthquakes (linear range))

10) Expensive, therefore only recommended in critical situations. Otherwise correlations for the non-linear behavior of geotechnical units are, in general, sufficient.

11) Correlation with shear wave velocity v_s only for preliminary studies.

12) The soil classification according to the Turkish Building Code as well as the NEHRP provisions, together with the calculation of the equivalent shear wave velocity $v_{s,30}$ (weighted average velocity in the upper 30m) will serve as validation and decision support for the preparation of the ground shaking microzonation map (Chapter 2.8.3).

Presentation of results

These intermediate results will be mapped according to Chapter 2.7.8.

2.7.6 Raw Data for the Preparation of the Liquefaction Susceptibility Map

General comments

The **liquefaction susceptibility map** presents the liquefaction potential at grid points and selected other profiles.

To define the liquefaction susceptibility, the following input data are needed:

- Local hazard at soil surface (result of the ground shaking map (at surface)
- Depth of groundwater table
- Material strength behavior under cyclic loading (several correlation methods exists)
- Soil stratification

Several techniques are available to assess the liquefaction susceptibility. For microzonation purposes, correlations with in-situ tests (SPT, CPT) are generally acceptable (Chapters 2.12.1 and 2.12.2).

Additionally, all already identified areas with known liquefaction susceptibility should be mapped.

Input data: local hazard at surface at grid points

Results from ground shaking map (p.g.a), and magnitude M_w of characteristic earthquake for the average return period of 100 years at grid point. The magnitude M_w defines implicitly the duration of strong motion.

The characteristic earthquake is derived by deaggregation of the regional hazard calculation (recommended). If no deaggregation results are available, M_w is taken to 6.5. This is a conservative value.

Recommended methods to obtain input data of soil profile at grid point

Needed Results	***Recommended Methods***	***Chapter***
Groundwater table	- Boreholes and/or geoelectric soundings, CPTU [1)]	2.12.1 2.12.8
Geotechnical properties of soil layers - Classification, grain size distribution, Atterberg limits, relative density	- Standard geotechnical test methods [2)] - Approved correlations with geotechnical units or in-situ tests [2)]	-
Material strength with respect to liquefaction	- Laboratory tests [3)] - Correlations with SPT [4)] - Correlations with CPT [5)]	- 2.12.1 2.12.2

Comments

[1] All methods suitable.

[2] Standard geotechnical laboratory tests are recommended. Correlations with geotechnical classification (TS 1500) are possible, but less accurate.

[3] Dependent on sample quality. As such, field data are more reliable.

[4] Highly recommended method, since large databases are available.

[5] Recommended method. Smaller databases are available, but somewhat less reliable than SPT.

Presentation of results

These results will be mapped according to Chapter 2.7.8.

2.7.7 Raw Data for the Preparation of the Landslide and Rock Fall Hazard Map

General comments

The **landslide and rock fall hazard map** presents the landslide and rock fall potential at grid points and selected other profiles.

To get the landslide and rock fall hazard, the following input data are needed:

- Local hazard at soil surface (result of the ground shaking map (at surface)
- Topography
- Material strength

Additionally, all already identified existing unstable areas should also be mapped (in already existing unstable areas, instabilities are enhanced due to earthquake). Experience shows that earthquake induced landslides mainly occur in areas with unfavorable geotechnical conditions already exhibiting creep or minor slope instabilities.

Input data: local hazard at surface at grid points

Results from ground shaking map (p.g.a., Chapter 2.7.5).

Recommended methods to obtain input data of soil profile at grid point

Essential Results	***Recommended Methods***	***Chapter***
Slope inclination map	- The basic topographic information (topographic map at scale 1:5,000) is provided by the municipality	-
Geological/Geotechnical soil layers	- Geological site investigation - Geotechnical site investigation	-
Material strength in respect of soil stability. Angle of internal friction. **(in areas with slope inclination > 15%)**	- Standard geotechnical test methods [1] - Correlations with geotechnical units or in-situ tests [1]	- -

Comments

[1] Standard geotechnical laboratory tests are recommended. Correlations with geotechnical units (USCS) tests are possible, but less accurate.

Important Issues

The question of slope instabilities due to earthquake effects is still an area of development. The method proposed here is a very crude method, and may not always lie on the conservative side. In water-saturated sands, even thin sand lenses may partially or totally liquefy, resulting in instabilities even at very low slope inclinations. To identify such small sand layers (which have to be saturated) very careful and detailed investigations would be needed, and is only recommended in areas where such conditions are expected.

Presentation of results

These intermediate results will be mapped according to Chapter 2.7.8.

2.7.8 Raw Data for the Preparation of the Earthquake-related Flooding Map

Data

- Flooding areas due to tsunamis and seiches requires specialized investigations.
- Flooding areas due to dam break should be obtained from upstream dam owner or the safety related governmental authority.

2.7.9 Mapping of Raw Data

Results and presentation

All of the raw data available (according to Chapter 2.6 to 2.7.8) are mapped **as layers of the topographical map,** with corresponding locations and attributes.

Attributes are for example:

- Soil classification according to the Turkish Building Code
- Soil classification according to the NEHRP provisions
- Equivalent shear wave velocity $v_{s,30}$
- Groundwater table
- Depth of engineering bedrock or competent soil layer
- Slope inclination values
- Etc.

2.8 Derivation and Creation of Microzonation Maps

2.8.1 Basic Steps

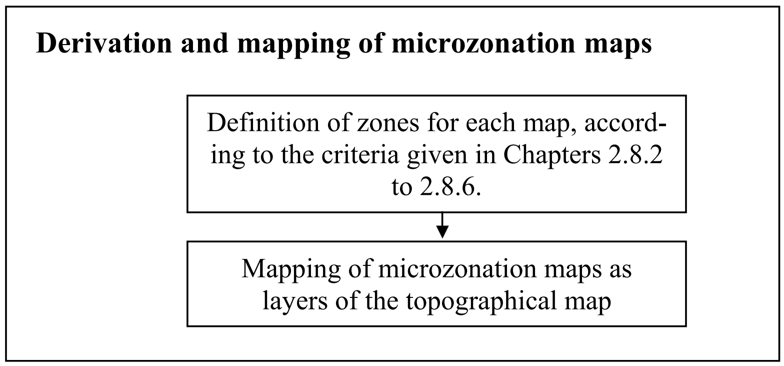
General

The described procedures in chapters 2.6 and 2.7 provide detailed data first at grid points.

These data have to be transferred to different zones (two or three zones for each earthquake effect), called "microzones," which represent similar values of the corresponding earthquake effect.

Steps

The following steps should be followed when deriving and mapping the microzonation maps:



Zones

In general, three zones are defined for every earthquake effect. For surface faulting and earthquake-related flooding, only two zones are defined, without an intermediate zone.

	Zone		
Effect	*High*	*Medium*	*Low*
Surface Faulting	A_{SF}	-	C_{SF}
Ground Shaking	A_{GS}	B_{GS}	C_{GS}
Liquefaction	A_{L}	B_{L}	C_{L}
Slope Instability	A_{SL}	B_{SL}	C_{SL}
Earthquake-related Flooding	A_{F}	-	C_{F}

<u>Surface faulting:</u>

A_{SF}: highest hazard, high probability of fault rupture at surface in an earthquake

C_{SF}: very low probability of fault rupture at surface

<u>Ground shaking:</u>

A_{GS}: relative highest shaking level, higher than average

B_{GS}: relative medium shaking level, slightly above average

C_{SF}: relative low shaking level, slightly below average

<u>Liquefaction:</u>

A_{L}: high susceptibility for liquefaction

B_{L}: medium susceptibility for liquefaction

C_{L}: very low susceptibility for liquefaction

<u>Landslides and rock fall:</u>
A_{SL}: high hazard for landslides and rock fall
B_{SL}: medium hazard for landslides and rock fall
C_{SL}: very low/no hazard for landslides and rock fall

<u>Earthquake-related flooding:</u>
A_F: highest hazard, high probability of earthquake-related flooding
C_F: no hazard of earthquake-related flooding

2.8.2 Surface Faulting Map

Recommended methods

Surface faulting can be different for each earthquake. Therefore, an uncertainty exists in defining zones. It is recommended to map faults locations, where faulting up to the surface has been documented several times in past earthquakes.

These locations can be attributed to zones with high influence (Zone A_{SF}), and are open only for restricted building activities.

The remaining areas are attributed to zones C_{SF} (low influence).

2.8.3 Ground Shaking Map

Results and presentation

Result:
Graphical representation of three different zones defined according to the criteria given below. It should be kept in mind that these zones represent the <u>relative</u> shaking hazard in relation to the whole investigated area.

Recommended evaluation techniques and criteria for zones

Definition of three zones with respect to average spectral accelerations determined from site response analysis.

The following steps should be performed at each grid point *i*:

1. Calculate the output response spectra at surface, for both input motions (according to Chapter 2.12.9).
2. Calculate the geometric mean of the two output response spectra. This leads to a "mean output response spectrum."

   Take the average (arithmetic mean) of the mean output response spectrum for the spectral range 0.5 to 1.5s. This average value is called S_i and will represent the plateau in the output acceleration response spectra for grid point *i*.

After calculating the above defined average values S_i at each grid point, three ground shaking zones are defined as follows:

1. Calculate the 33% and 67% percentiles of all average values S_i for the whole investigated area. These percentiles are called $S_{(33\%)}$ and $S_{(67\%)}$.
2. A zone is assigned at each grid *i* depending on the value of S_i at the corresponding grid:

Zone	Criteria
A_{GS}	$\mathbf{S_i} \geq S_{(67\%)}$
B_{GS}	$S_{(67\%)} > S_i > S_{(33\%)}$
C_{GS}	$\mathbf{S_i} \leq S_{(33\%)}$

A three zone differentiation (A/B/C) as described above is justified only if $S_{(67\%)} > 1.3\ S_{(33\%)}$. If this is not the case, it is recommended to define in an analogous way only two zones A_{GS} and C_{GS}, where zone A_{GS} represents values S_i above 50% percentile and C_{GS} values S_i below 50% percentile.

Validation and comparison of results

The spectral amplification functions or response spectra can be derived in different manners. Important information can also be retrieved from local recordings of earthquakes by temporary or permanent stations (seismological or accelerometric). If available, such information should be used for the validation of the results for ground shaking hazard.

Apart from the calculation based on site response analyses as described above, other approaches are available, which can serve as comparison and validation of the results:

- Results of microtremor measurements
- Based on Turkish code or NEHRP
- Based on the equivalent shear wave velocity (Midorikawa (1987).

The final mapping with respect to ground shaking can be accomplished by comparing the average spectral accelerations obtained by site response analyses with the peak spectral amplifications calculated using equivalent shear wave velocity based on by Midorikawa (1987).

There are basically two possibilities in making the comparison between the average spectral accelerations obtained by site response analysis (let call the corresponding zones A_S, B_S and C_S) and peak spectral amplifications obtained from equivalent shear wave velocities (let call the corresponding zones A_V, B_V and C_V):

1. The first option is to use the maps obtained for both parameters and determine the overlapping zones graphically using the GIS program. In the procedure that can be followed in carrying out this assessment, and since both maps are divided in to three zones, it is also essential to have three zones again in the final map:
   - The zone A_{GS} corresponds to overlapping zones of A_S and A_V or A_S and B_V or B_S and A_V.
   - The zone B_{GS} corresponds to overlapping zones of A_S and C_V or C_S and A_V or B_S and B_V.
   - The zone C_{GS} corresponds to overlapping zones of B_S and C_V or C_S and B_V or C_S and C_V obtained from both approaches.

Due to the methodology followed for the graphical evaluation, the final map can only be obtained in terms of clear boundaries.

2. The second alternative is to perform this assessment for each grid numerically by adopting the above criteria to determine the three zones and then perform the mapping using the new data.

Since it is easier, faster and less susceptible to errors, and since it leads to soft boundaries, it is recommended that the second alternative to obtain the ground shaking zonation map be adapted.

2.8.4 Liquefaction Susceptibility Map

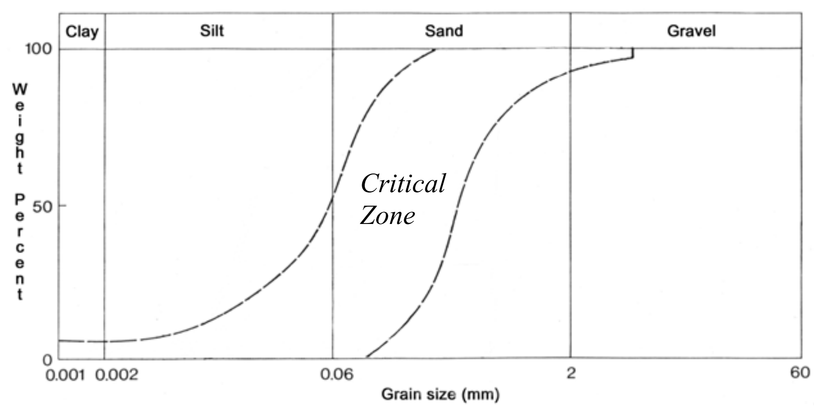
Results and presentation

Result:
Graphical representation of three different zones defined according to the criteria given below.

Zone
A_L: High susceptibility
B_L: Medium susceptibility
C_L: Low susceptibility

Critical Zone of Grain Size Distribution

A critical zone within the grain size distribution diagram is defined as follows:



The above critical zone was derived according to experience with liquefaction of soils worldwide [Finn (1972)].

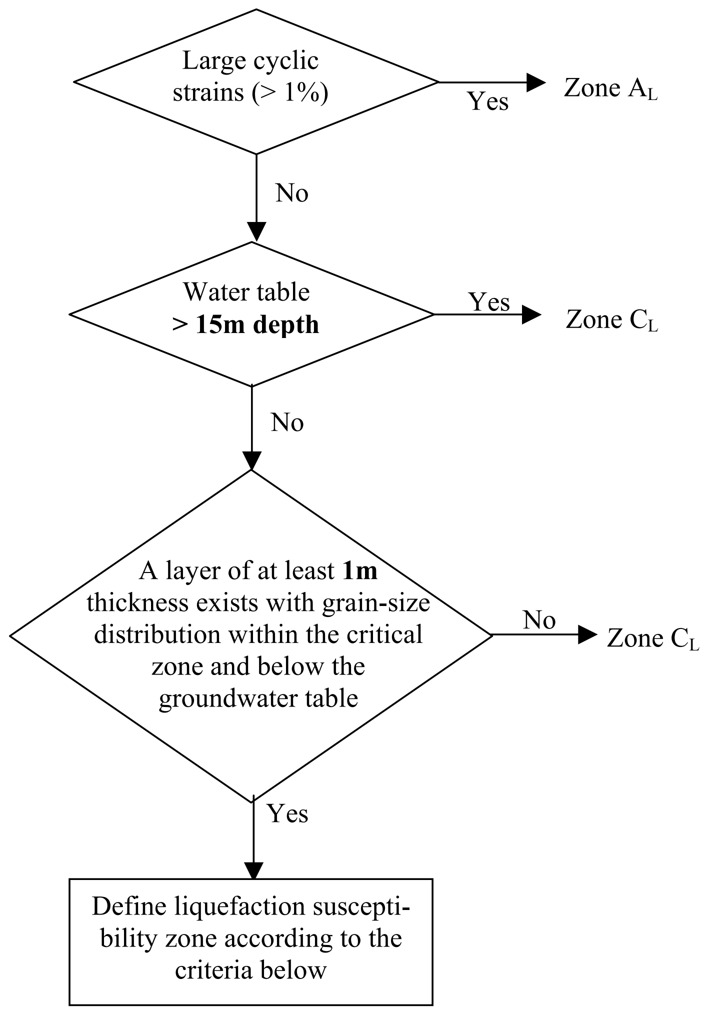
The grain size distribution curve of a given soil is said to be within the critical zone, if this curve lies fully in the critical zone within the range of 5% to 90% weight (by using engineering judgment in special cases).

Preliminary results from site response analysis

A potential problem arises in strata with very low shear wave velocity. The site response analysis calculation (using an equivalent linear procedure) may predict large (1% or more) cyclic strains and hence great loss of stiffness. The result can be very small computed acceleration at ground surface. Such a large "deamplification" of motions indicates a significant loss in strength and stiffness. Although this is not liquefaction in a strict sense, where this problem occurs, the corresponding grid point is classified in zone A_L.

Recommended evaluation techniques and criteria for zones

The following procedure is recommended to define the Susceptibility Zone A_L, B_L or C_L:



Recommendations to select the appropriate method

SPT tests are preferred instead of CPT tests since better correlations with the liquefaction susceptibility exist. Laboratory tests are not very suitable, since they are expensive, and furthermore the results are not necessarily reliable due to the inevitable disturbance of the samples.

SPT method

- SPT tests

The liquefaction susceptibility is based on the calculation of the safety factors FS as described in Chapter 2.12.2.

After calculating the factors of safety for all liquefiable layers, the "liquefaction potential index" P_L is calculated for the first 20m below ground surface:

$$PL = \int_0^{20} (1 - FS)\, w(z) dz$$

where z is the depth below the ground surface, measured in meters, FS the factor of safety at z, and w(z) = 10-0.5z. The factor (1-FS) is considered to be 0 if it is negative.

Three liquefaction susceptibility zones are then defined as follows:

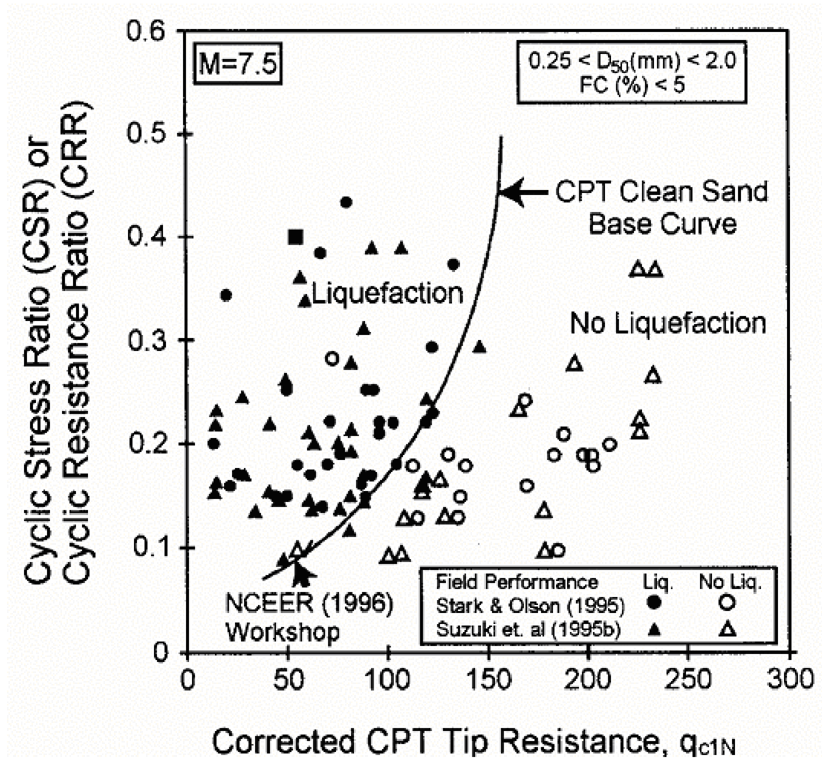
Zone	**Criteria**
A_L: High susceptibility	**PL > 15**
B_L: Medium susceptibility	**5 ≤ PL ≤ 15**
C_L: Low susceptibility	**PL < 5**

Key references can be found in Iwasaki et al. (1982), Seed et al. (2000) and Youd et al. (2001).

CPT method

- CPT tests

  The liquefaction susceptibility is assessed with the aid of the following figure (Youd, TL., Idriss, LM., et al. (2001), for details see Chapter 2.12.1).



Zone	Requirements
A_L: High susceptibility	**"Liquefaction zone" according to above figure: corresponding points lie above, and to the left of, the CPT clean sand base curve.**
B_L: Medium susceptibility	-
C_L: Low susceptibility	**"No liquefaction zone" according to above figure: corresponding point lies below the CPT clean sand base curve.**

Remark: the above criteria define only two zones for liquefaction susceptibility.

2.8.5 Landslide and Rock Fall Hazard Map

Results and Presentation

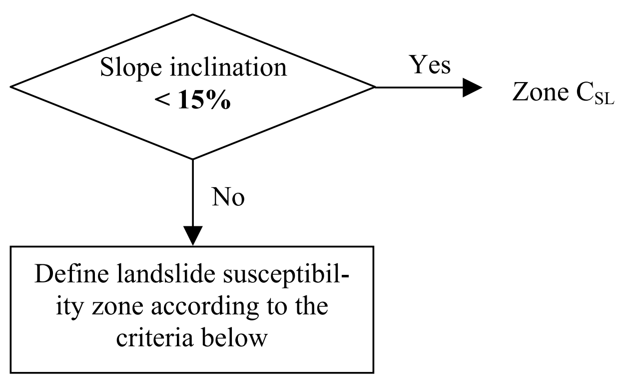
Result:
Graphical representation of three different zones defined according to the criteria given below.

Recommended Evaluation Techniques and Criteria for Zones

Definition of three zones of different landslide and rock fall hazard, according to the calculated factor of safety Fs as defined in Chapter 2.12.11.

This procedure gives sufficiently accurate results at relatively low cost. In areas with very complex geotechnical conditions, particularly with loose cohesionless layers and high groundwater table or areas with extremely weathered rocks, more detailed analyses may be necessary. For long slopes ("infinite slopes") shallow surface layers my fail by sliding on a failure surface parallel to the slope. In case of the existence of infinite slopes in the investigated regions, the use of sliding block analysis is recommended.

In cases where the slope can be modeled as a finite slope, landslide and rock fall hazard zones are defined as follows, with the simplified procedure in Chapter 2.12.11:



Zone	Criteria
A_{SL}: High hazard	**Fs ≤ 1.0**
B_{SL}: Medium hazard	**Fs between 1.0 and 2.0**
C_{SL}: Low hazard	**Fs > 2.0**

Special conditions need to be considered in case of liquefiable layers located within slopes with lower inclination. If such conditions exist, slopes with a slope inclination smaller than 15% can also become instable.

Procedure for Existing Slope Instability Zones

It is recommended that existing instability zones be also included in this map. The hazard for increased sliding during an earthquake is high in such zones. These zones should be incorporated in the "high hazard" zone A_{SL}.

2.8.6 Earthquake-related Flooding Map

Results and Presentation

Result:
Graphical representation of two different zones defined according to the criteria given below.

The following effects are taken into account:

- Potential flooding areas due to a dam break upstream of the investigated area. These data should be collected from the owners of upstream dams or the governmental agency responsible for dam safety.
- Flooding due to earthquake induced waves (mainly tsunamis along the sea coasts). These data should be requested from GDDA.

Recommended Evaluation Techniques and Criteria for Zones

Definition of two different zones of earthquake-related flooding potential, according to the criteria given below.

Zone	**Criteria**
A_F: High hazard	Potential flooding areas from the database mentioned above.
C_F: Low hazard	Other areas.

Remark: this map is only needed if such hazards are possible.

2.8.7 Mapping of Hazard Zones

The procedures described above to define hazard zones provide detailed data first at grid points. To get lines of equal values (isolines), linear interpolation between the grid points can be used. There are several software tools which perform this task (e.g. "GMT Generic Mapping Tools", School of Ocean and Earth Science and Technology University of Hawaii, USA, 2002). Extrapolation to areas where no data are available should be avoided.

It has to be noted that the boundaries between the defined zones are not sharp boundaries, due to the inherent uncertainties in the different steps leading to these zones. The zones in the microzonation maps should rather be treated with "soft" boundaries, applying appropriate judgement when considering these maps for developing land use management plans. A comparison with the surface geology can also serve as a decision aid for land use management.

2.9 Recommendations to Develop Zone-Associated Building Regulations

Types of recommendations for individual zones

Zone-specific building regulations should reflect the degree of hazard and give indications for additional investigations to assess more reliable design criteria. **In general, structures can be built in all zones, provided that appropriate measures are taken to encounter the different earthquake hazards.** Zone-associated building regulations are only one among several criteria which will lead to a sustainable land use management in a municipality.

Recommendations are most effective in areas where building activities do not exist yet, so they can serve as **an effective land use management guide and city planning of still unpopulated areas**. But these recommendations can also serve as guide (for areas with already high building concentration) for an **enhancement of the future land use management and city planning**, as well as for the **identification of potential high-risk zones**. Recommendations are in general stricter for new structures, due to the fact that earthquake resistant design has nearly no impact on the total construction costs (about 3% to 4%), whereas for existing structures, upgrading costs can be significant. For existing structures, upgrading should be based on risk-dependent criteria.

Microzonation is related to land use management and city planning, and not to design of structures:

- **Microzonation is a powerful tool for land use management, to facilitate the city planning work of the responsible authorities. Zone-specific building recommendations provide guidelines for additional investigations to define the design input appropriately.**
- **The microzonation results are not related to the Turkish Building Code. The Turkish Building Code defines minimum requirements, which always have to be fulfilled.**

The recommendations concentrate on areas with residential and office buildings, since the municipalities mainly deal with those areas. But the recommendations can and should be applied in the same way for infrastructures like schools, police stations, hospitals, etc.

Definitions

In the recommendations given in this chapter, the following terms are used:

- "Important buildings/structures": Public buildings/structures with major importance for the Municipality.
- "Hazardous industries": Mainly chemical industries with hazardous materials. Damage of these industries can lead to serious damage to people or environment.
- "Risk dependent safety level": The required safety level should reflect the earthquake hazard as well as the potential effects of earthquake-caused uncontrolled release of hazardous substances on population and environment.
- "Critical infrastructure": Infrastructure elements (line elements or objects) that are of vital importance for the corresponding infrastructure system. A failure of these elements will cause collapse of large part of the system. If so called "important infrastructure elements" fail, the system will collapse at least temporarily. (See also chapter 2.11.1)
- "Short term": In the range of 10-20 years.

Surface Faulting Zones

Zone	
A_{SF}	**In terms of city planning, this zone is not recommended for dense population and important structures.** Recommendations: - New larger residential buildings, important office buildings, schools etc. with high occupancy should be avoided. For existing buildings of this type, special risk-oriented investigations should be performed and adequate measures should be taken. - New hazardous industries (larger chemical facilities) should be avoided. For existing hazardous industries, an acceptable, risk-dependent safety level should be defined. The vulnerability of the facilities should be evaluated and compared with the required safety level. If needed, existing structures should be upgraded or taken out of service. - Critical infrastructure elements (linear elements) should be avoided, since these elements often cannot withstand the deformations occurring in this zone. If this is not possible, special measures should be taken to ensure that the potential deformations can be survived.
C_{SF}	No specific recommendations.

Ground Shaking Zones

Shaking hazard can be a single hazard or combined with liquefaction or slope instabilities!

Zone	
A_{GS}	**In terms of city planning, this zone is not recommended for dense population and important structures.** Recommendations: - New larger residential buildings, important office buildings, schools etc. need site-specific investigations to assess the shaking level. For the design, this shaking level should be taken into account, if the shaking level lies above the Turkish Building Code requirements. - Existing buildings of this type should be given the priority to be evaluated (taking site-specific conditions into account) and upgraded in the short term if needed. - New hazardous industries should be avoided. - For existing hazardous industries, an acceptable, risk-dependent safety level should be defined. The vulnerability of the facilities should be evaluated and compared with the required safety level. If needed, existing structures/facilities should be upgraded or taken out of service. - New critical infrastructure objects should be avoided. For existing critical infrastructure objects, specific site investigations should be performed. If needed, the structures should be upgraded.
B_{GS}	Recommendations: - Existing larger residential buildings, important office buildings, schools etc. should be evaluated and upgraded if needed. - For new and existing hazardous industries, an acceptable, risk-dependent safety level should be defined. The vulnerability of the facilities should be evaluated and compared with the required safety level. If needed, existing structures/facilities should be upgraded or taken out of service. - For new and existing critical infrastructure objects, specific site investigations should be performed. The vulnerability should be evaluated. If needed, existing structures should be upgraded.
C_{GS}	No specific recommendations.

Liquefaction Zones

Liquefaction hazard is always accompanied by ground shaking hazard.

Zone	
A_L	**In terms of city planning, this zone is not recommended for dense population and important structures.** Recommendations: - New larger residential buildings, important office buildings, schools etc. need site-specific investigations to assess liquefaction susceptibility. If liquefaction potential is significant, particular foundation design should be provided (e.g. piles, ground improvement). - Existing larger residential buildings, important office buildings, schools etc. should be evaluated (taking site-specific conditions into account) and foundations upgraded in the short term if needed. - For new ordinary buildings, the design of the foundations should be based on a geotechnical report prepared by a qualified geotechnical engineer or engineering geologist. - New hazardous industries should be avoided. Existing structures should be evaluated for liquefaction potential by a site-specific study and adequate foundation measures should be designed accordingly. - New critical infrastructure (linear element and objects) should be avoided. If this is not possible, redundancies should be created in order to avoid the collapse of the system. For existing critical infrastructure, liquefaction should be assessed by site-specific studies and adequate foundation measures should be implemented in the short term if needed.
B_L	Recommendations: - New larger residential buildings, important office buildings, schools etc. and hazardous industries need site-specific investigations to assess liquefaction susceptibility. If liquefaction potential is significant, particular foundation design should be provided (e.g. piles, ground improvement). - Existing larger residential buildings, important office buildings, schools etc and hazardous industries should be evaluated (taking site-specific conditions into account) and foundations upgraded in the short term if needed.
C_L	No specific recommendations.

Landslides and Rock fall Zones

Landslides and Rock Fall hazard is always accompanied by ground shaking hazard.

Zone	
A_{SL}	**In terms of city planning, this zone is not recommended for dense population and important structures.** Recommendations: - Larger residential buildings, important office buildings, schools etc. should be avoided. For existing structures with high occupancy, landslide and rock fall hazard should be assessed by a site-specific study. - For ordinary buildings, particular investigations and design criteria should be based on a geotechnical report prepared by a qualified geotechnical engineer or engineering geologist. - New hazardous industries should be avoided. For existing structures, landslide and rock fall hazard should be assessed by a site-specific study and adequate measures should be designed accordingly. - Critical infrastructure (line elements and objects) should be avoided. If this is not possible, redundancies should be created in order to avoid the collapse of the system. For existing critical infrastructure, landslide and rock fall hazard should be assessed by site-specific studies and adequate measures should be designed accordingly.
B_{SL}	Recommendations: - Larger residential buildings, important office buildings, schools etc. should be avoided. For existing structures with high occupancy, landslide and rock fall hazard should be assessed by a site-specific study. - For ordinary buildings, particular investigations and design criteria should be based on a geotechnical report prepared by a qualified geotechnical engineer or engineering geologist. - For hazardous industries, landslide and rock fall hazard should be assessed by a site-specific study and adequate measures should be designed accordingly.
C_{SL}	No specific recommendations.

Flooding Zones

Zone	
A_F	**In terms of city planning, this zone is not recommended for dense population and important structures.** Recommendations: - New larger residential buildings, important office buildings, schools etc. should be avoided. For existing structures of this type, special risk-oriented investigations should be performed. - New hazardous industries should be avoided. For existing structures special risk-oriented investigations should be performed. If needed, the structures should be taken out of service.
C_F	No specific recommendations.

2.10 Preparation of the Microzonation Report and its Submission to the Approving Agency

General

The following criteria are given:
- To guarantee a general, comparable minimal quality of microzonation studies all over Turkey.
  - So that microzonation projects in all areas are comparable.
  - So that municipalities and approving agency have a common understanding
- For a better comparison of different studies based on common report structure and map presentations.

Content and criteria

The report submitted to the approving agency should have the following structure:

<u>Introduction</u>
- General description of the areas selected for microzonation.
- Basic topographic maps of the investigated areas
- If available, additional information like aerial photographs showing the built-up area (residential zones, industrial zones etc.), maps showing the population density, etc. can be valuable tools in assisting in the final stage the establishment of the land use management plan.

<u>Geological and geotechnical characteristics of investigated areas</u>
- Description of geology
- Main geological/geotechnical properties of formations

<u>Assessment of the regional hazard</u> (based on Chapter 2.5)

This chapter should include:
- Methodology used
- Results
- Regional Fault Map, Tectonic Map
- Historical Seismicity
- Regional Hazard Map/Data on competent soil layer (pga and spectral acceleration values)

<u>Basic existing data and additional investigations</u> (based on Chapter 2.6)
- Seismological and Geophysical Data
- Geotechnical Data
- If available, additional investigations performed for the on-going study, based on the results needed for the preparation of the microzonation maps, including interpretation and discussion of the results of the additional investigations

These chapters should include:
- Overview of the data, identification of data source, representativeness and quality control procedure
- Interpretation and discussion of findings, including estimation of uncertainties and weak points
- Possible improvement actions planned to improve database for future revisions
- Data recommended to be collected by the municipality
- Recommendations for further investigations and studies

Derivation and creation of microzonation maps (Based on Chapter 2.8)

This chapter should include:

- Procedures used for the derivation of the required microzonation maps (site response analyses, liquefaction assessment, landslide hazard)
- Estimation of uncertainties and weak points

Investigation of structural damage

If available, this chapter should include:

- Investigation of damage distribution from past earthquakes
- Interpretation and recommendations in terms of:
    - Properties of structures
    - Soil characteristics

Creation of microzonation maps

- Description of mapping procedures and criteria for zones
- Maps:
    - Surface faulting map
    - Ground shaking map
    - Liquefaction susceptibility map
    - Landslide and rock fall hazard map
    - If needed, earthquake-related flooding map

References

2.11 Recommendations for Additional Use of Microzonation Maps (Guidelines for Companies Commissioned to Perform such Studies)

2.11.1 Microzonation as Basis for Setting Priorities in Reducing Vulnerability of Critical Infrastructure

Definition of Critical Infrastructure System

The behavior of the infrastructure in an earthquake event is the backbone for economic development in an area, but also for the response of intervention forces in case of an event. Critical infrastructure in this content means the entire infrastructure that "controls" the response of the intervention forces and the reconstruction after the event.
Examples are:

- Command and control centers (police, fire departments etc.)
- Emergency hospitals (not every hospital)
- Supply and disposal system (e.g. water, energy, food etc.)
- Transportation system
- Telecommunication system

It has to be kept in mind that the functionality of the system is important, and not only the structural integrity.

For each system, the minimum functional mode should be defined for a selected earthquake scenario (e.g. return period 500 years). 500 years is equal to 10% of the probability of exceedance in a period of 50 years, 50 years is taken as the lifetime of a structure.

It is reasonable to define this functional mode lower than in ordinary service time.

Definition of Important Categories in an Infrastructure System

Each infrastructure system to be investigated should be divided into elements (e.g. general and local command and control center, substations, connecting lines, etc.).

Each element is classified with the following criteria:

1. **Class I: Most important elements.**
   If such an element fails, the entire system will at least temporarily break down. This could be the main control center, a single energy feeder line without any redundancy.
2. **Class II: Important elements.**
   If such an element fails, the system will at least fail in an area of importance, e.g. fraction of a town. The system as a whole will not be affected.
3. **Class III: Less important elements.**
   If such an element fails, only local damage will occur, but the system as a whole will not be affected.

Assessment of the hazard for each element

The infrastructure system with all its elements should be overlapped by the individual hazard maps (fault, shaking, liquefaction, landslide, flooding). This will define the hazard at each individual element.

Evaluation of the general vulnerability

The general vulnerability of each element depends on the type of the element (buried line element, above ground line element, buried structure, above ground structure).

Line elements are particularly vulnerable to deformations of the surface. Such deformations have to be expected in areas with medium and high susceptibility for slope instabilities and liquefaction, as well as in active surface fault zones. Therefore, elements of Class I should not be located in such zones.

Above ground structures are mainly vulnerable to shaking, but also to deformations due to liquefaction and slope instabilities.

Further criteria are:

- Age of element and if earthquake resistant design existed at this time and was taken into account.
- Type of structure and its materials (e.g. ductility).

The vulnerability of each element of Class I should be assessed according to the above-mentioned general criteria.

A simple tool to estimate damage of structures based on intensities is the EMS-98 scale (chapter 2.11.4).

Priority setting for risk reduction

The procedure described above only provides a ranking for further investigations. More detailed investigations, which take local geological situations and structural elements into account, should now be performed, to assess the real risk of failure and to define alternatives to reduce this risk.

Often, it cannot be avoided that important elements are located in high hazard zones, and the actual risk of failure is unacceptable. In such cases, not only upgrading of an element can be the solution, but also providing redundancies, which can be economically advantageous.

2.11.2 Microzonation as Basis for Assessment of the Capacity of Intervention Forces

General

Worldwide experience from larger past earthquakes show that intervention forces are in general overloaded by the amount of imprecise, unexpected information and situations. It is obvious that the effect of a specific event cannot really be predicted. But, good preparation will lead to less overwhelming situations. The preparedness should include the following topics:

- Assessment of center of damage for specific scenarios. Assessment of potential number of victims, capacity needed for search and rescue, first aid capacity needed, number of homeless.
- In which scenarios own intervention forces are sufficient, where outside help is needed. Have the own intervention forces the capacity (personnel and equipment) and the training needed? Build up a training program for involved staff.
- Preparation of conditional decision schemes/checklists. If such decision schemes/checklist exist, they can be modified easily and quickly and altered to the actual situation. Types of such decision schemes are for instance: type of intervention (strategy, capacity, resources) and access routes to highly vulnerable or hazard zones, or lists of food/water, shelter, required for 1,000 homeless persons etc.
- Training of the whole system divided in decision-taking training of the involved staff in case of an event, and training of search and rescue teams in simulated damage places.

In a pragmatic way, the needed capacity of intervention forces can be assessed on the basis of microzonation maps.

It is recommended to follow the following steps:

1. Define zones in the construction areas with structures of similar vulnerability, e.g. old town center, residential areas with new buildings of same construction type and similar height, industrial areas, etc. (a good tool for a pragmatic approach are the vulnerability classes of EMS-98, chapter 2.11.4)
2. Identify locations of important elements of critical infrastructure, e.g. emergency hospitals, fire stations, important transmission stations, bottle-necks in transportation system (important bridges, tunnels, important streets in densely populated areas).
3. Assess, in a pragmatic way, the vulnerability of the zones defined in item 1, based on vulnerability classes of EMS-98.
4. Select a scenario based on experience (e.g. EMS-98 intensity to be expected for an earthquake with a certain return period).
5. Use the definition in the EMS-98 scale together with the intensity of the scenario earthquake and the vulnerability of the zones to assess the damage grade and extent.
6. A general concept for the intervention forces can be evaluated based on the results of item 5.

Basic Information Sets

Microzonation, even when applied to land use management, is one of the basic information sets (in addition to population and industrial distribution, vulnerability of residential and industrial zones, location of critical infrastructure etc.) needed for the assessment of the capacity of intervention forces.

2.11.3 Assessment of Damage after an Earthquake Event

Purpose

The primary purpose of emergency damage inspection is to protect human lives and to prevent injuries by identifying buildings that have been weakened by the earthquake and are therefore threatened by subsequent aftershocks. The other important objective of this operation is to avoid unnecessary wasting of resources by singling out habitable and easily repairable buildings. A parallel goal is the quantification of structural damage in a structure after it has been exposed to a given ground motion, so that projections useful for constructing vulnerability curves or insurance loss models can be obtained.

Emergency Post Earthquake Damage Assessment

When a strong earthquake strikes a populated area, buildings may suffer damage of various degrees, occasionally leading to a partial or complete collapse. Building officials and damage inspection teams are then faced with complex circumstances when they must make quick and reliable judgments in assessing the degree of damage, the safety and the usability of these buildings. This operation is referred to as Emergency Post Earthquake Damage Assessment (or EPEDA). It typically consists of a quick reconnaissance of the buildings in the area, to determine whether they can still serve the functions they had been designed for without a substantial reduction in the safety conditions required for human occupancy.

An official procedure exists for this purpose, with an associated damage assessment form and related software to evaluate the collected data.

EPEDA form

The visible part of EPEDA consists of a form with questions for the inspector to answer, and a booklet that serves as a background tool. Some of the questions in the form are answered with the aid of iconized diagrams drawn in detailed form in the booklet, and supported by verbal explanations based on structural theory and empirical data. The questions fall into four major categories:

- Administrative information (ownership, address, casualties, etc.)
- General information (geometric/architectural characteristics, structural features, irregularities, spans, etc.)
- Load-resisting mechanism features (type of framing, wall-frame, or box, type of floor system, whether poured in place or prefabricated, partition wall strengths, type of foundation system, workmanship quality, etc.)
- Attributes of damage and their extent for each type of member for each damage category (permanent drifts, wall crack widths, visible cracks in the horizontal and vertical members, etc.).

The form is designed to work also in conjunction with a renewable relational database.

Methodology

The methodology embedded in EPEDA is based on the notion of **Global Damage State (GDS)**, which is a qualitative measure of the safety of the building under inspection.

The damage state associated with the building is the result of a consistent reasoning involving three principal elements:

- Evidence derived from the geotechnical state of the local site conditions in the immediate vicinity of the building and its foundations system
- The state of the structural system
- Additional hazards represented by its deformed configuration.

Simple software has been coded to facilitate both the entering of data from inspectors and calculation of scores for streets, districts, cities or regions.

Results

The Global Damage State directly dictates the decision that should be taken regarding the continued use of the structure:

- If it is **severe**, then the building should be immediately evacuated, and eventually demolished.
- If it is **slight**, then the building is declared as being safe for continued use, and may be occupied even as aftershocks are occurring.
- If it is in a state of **moderate** damage, then the building requires repair, and therefore can be occupied only after retrofit has been done.

Any of the outcomes may apply only to the entire building, and not to parts of it.

Form

The official form to be used is the "Damage Assessment Form for Engineered Buildings," Ministry of Public Works and Settlement, General Directorate of Disaster Affairs.

Mapping

The Global Damage State can be mapped as layer of the topographic map in order to show the three different zones for "slight," "moderate," and "severe" damage.

2.11.4 EMS-98 Scale

Purpose and use

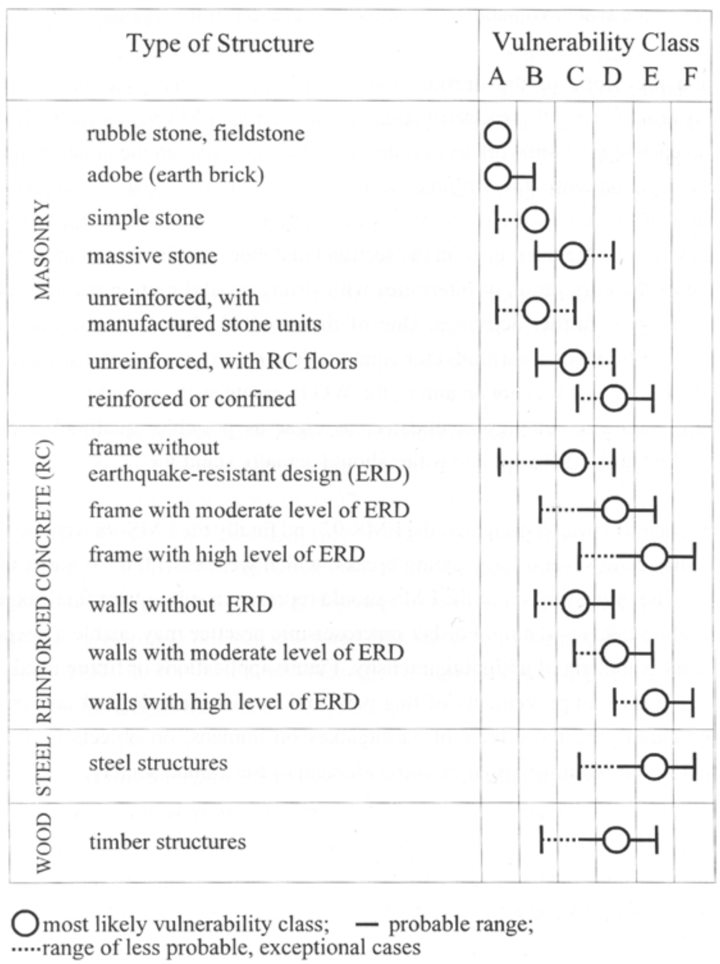
To assess damage for earthquake scenarios, intensity is a suitable and simple indicator. For such simplified scenario studies, it is recommended that the European Macroseismic scale 1998 (EMS-98) be used. The following uses are recommended here:

- Given a structure type and a damage grade, the corresponding earthquake intensity can be obtained
- Given an earthquake scenario (intensity) and a structure type, the probable damage grade for this specific structure type can be assessed

General Description of EMS Scale

The EMS-98 relates **Intensity** at a place with the **Damage Grade** of a specific structure, which is dependent on the vulnerability of the structure.

Six **Vulnerability Classes** (A to F) for corresponding building types are introduced for this purpose. The vulnerability class depends on the type of structure (masonry, reinforced concrete, steel, wood) and on the grade of earthquake resistant design (ERD) applied for the design of the structure. The grade of earthquake resistant design is dependent on the existing earthquake codes valid at construction time.



Relation between intensity and damage grade

Relations between the shaking intensity and the damage grade are further defined, depending on the vulnerability of the structure. In the following figure, an example for the range of intensity VII to IX is shown. The remaining detailed intensities can be found in the reference (EMS-98, 1998), also available as Internet download.

VII. Damaging

a) Most people are frightened and try to run outdoors. Many find it difficult to stand, especially on upper floors.
b) Furniture is shifted and top-heavy furniture may be overturned. Objects fall from shelves in large numbers. Water splashes from containers, tanks and pools.
c) Many buildings of vulnerability class A suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class B suffer damage of grade 2; a few of grade 3.
A few buildings of vulnerability class C sustain damage of grade 2.
A few buildings of vulnerability class D sustain damage of grade 1.

VIII. Heavily damaging

a) Many people find it difficult to stand, even outdoors.
b) Furniture may be overturned. Objects like TV sets, typewriters etc. fall to the ground. Tombstones may occasionally be displaced, twisted or overturned. Waves may be seen on very soft ground.
c) Many buildings of vulnerability class A suffer damage of grade 4; a few of grade 5.
Many buildings of vulnerability class B suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class C suffer damage of grade 2; a few of grade 3.
A few buildings of vulnerability class D sustain damage of grade 2.

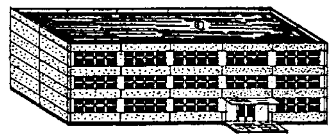
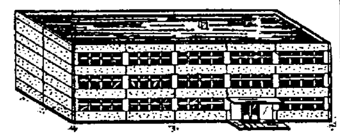
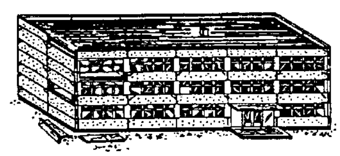
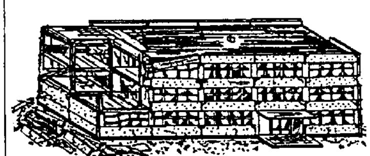
IX. Destructive

a) General panic. People may be forcibly thrown to the ground.
b) Many monuments and columns fall or are twisted. Waves are seen on soft ground.
c) Many buildings of vulnerability class A sustain damage of grade 5.
Many buildings of vulnerability class B suffer damage of grade 4; a few of grade 5.
Many buildings of vulnerability class C suffer damage of grade 3; a few of grade 4.
Many buildings of vulnerability class D suffer damage of grade 2; a few of grade 3.
A few buildings of vulnerability class E sustain damage of grade 2.

The principal effects of the earthquake are described for each intensity. The damage grade (ranging from 1 to 5) is given for buildings, depending on the vulnerability class.

Damage grades

The five damage grades are defined and illustrated in the EMS-98. In the figure below, an example of the illustration for reinforced concrete structures is shown. For masonry structures, the analogous damage grades can be found in the reference (EMS-98, 1998), also available as Internet download.

Classification of damage to buildings of reinforced concrete	
	**Grade 1: Negligible to slight damage** **(no structural damage,** **slight non-structural damage)** Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills.
	**Grade 2: Moderate damage** **(slight structural damage,** **moderate non-structural damage)** Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels.
	**Grade 3: Substantial to heavy damage** **(moderate structural damage,** **heavy non-structural damage)** Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of conrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels.
	**Grade 4: Very heavy damage** **(heavy structural damage,** **very heavy non-structural damage)** Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor.
	**Grade 5: Destruction** **(very heavy structural damage)** Collapse of ground floor or parts (e. g. wings) of buildings.

The damage grade ranges from negligible to destructive. In most international codes, the maximum allowed damage for structures should not be greater than grade 3, for the assumed earthquake level. For important structures and structures with high earthquake risk (e.g. chemical facilities, main infrastructure system, structures with high occupancy), often more severe criteria have to be fulfilled.

Correlation of Intensity with pga

The EMS-98 relates observed damage grades to corresponding intensities. Damage to a structure with certain dynamical properties depends on the amplitude, frequency content and duration of shaking, and only indirectly on the occurred peak ground acceleration. Therefore for a specific structure there can be no clear correlation to calculate the expected intensity (with corresponding damage grade) from peak ground acceleration or vice versa.

With a_h as the horizontal peak ground acceleration (in cm/s^2) and Intensity I as the EMS intensity, the following correlations can be used, with great prudence:

$$a_h = 10^{0.26 \cdot I + 0.19}$$

$$I = \frac{1}{0.26}(\log_{10} a_h - 0.19)$$

Examples:

- for a pga of 0.2g (=196cm/s^2), an intensity of 8.1 is obtained
- for an intensity of 9.0, a pga of 339cm/s^2 (=0.35g) is obtained.

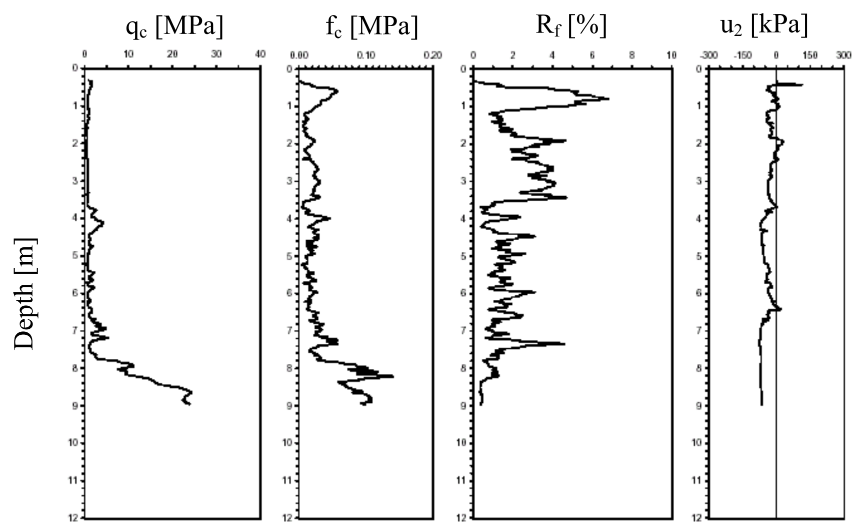
2.12 Annex: Recommendations for Data Assessment and Evaluation Procedures

2.12.1 CPT, CPTU and SCPT tests

Results and presentation

Results:
- Identification of soil layers
- Classification of soil layers
- Correlations with geotechnical and geophysical properties

Intermediate presentation of measurement data from a CPTU test, as a function of depth:



The above figures show the following data as a function of depth (from left to right):

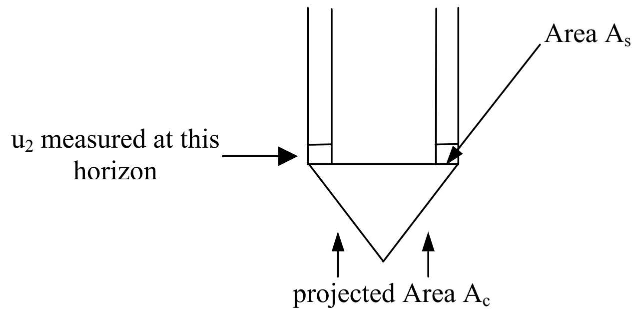
- Measured data for cone resistance q_c
- Measured data for sleeve friction f_s
- Calculated friction ratio $R_f = f_c / q_c$
- Measured data for pore water pressure u_2 (the pore water measurement can be done at different locations; if it is just above the cone as usual, it is in general called u_2, whereas u_1 and u_3 denote measurements at the tip or above the friction sleeve, respectively).

Short characteristics of the test procedure

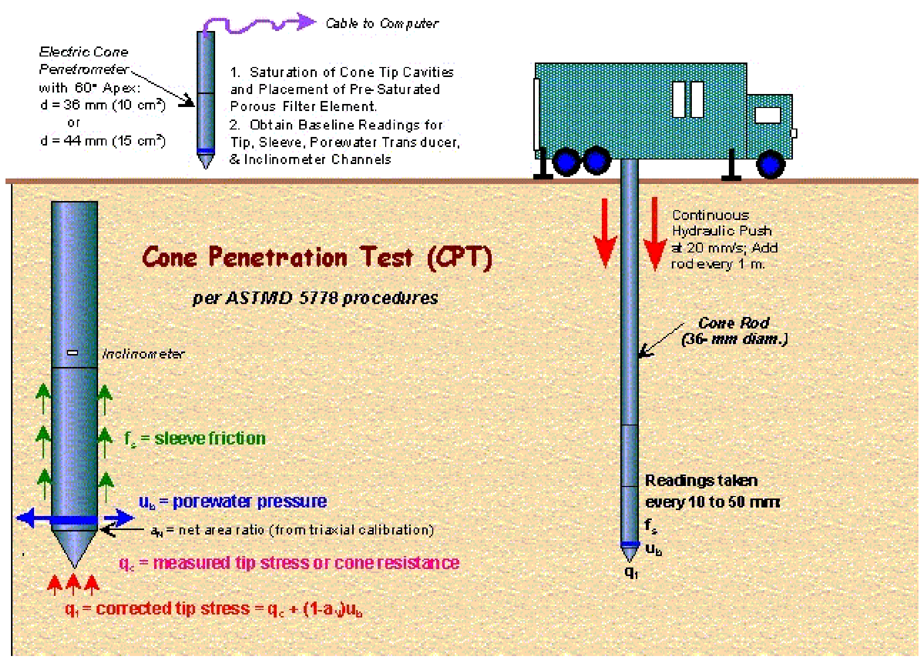
CPT with measurement of the pore water pressure (CPTU)

A CPT device consists of a cylindrical probe with a cone-shaped tip with different sensors that allow real-time continuous measurements by pushing it into the ground at a speed of 2 cm/s. The typical CPT probe measures the cone resistance q_c at the tip and the sleeve friction f_s.

CPTU cones additionally measure the pore water pressure u_2 just above the cone tip. By means of these data, the cone resistance q_c can be corrected to a total cone resistance q_T. Taking into consideration the geometry of the cone, this correction can be expressed as $q_T = q_c + (1\text{-}a)u_2$, where a denotes the area ratio A_s/A_c, with A_c as the total projected area (usually $10cm^2$) and A_s as the seal area above the cone tip. The following scheme illustrates the above relationship:



A field computer displays the data in real-time and stores it at regular depth intervals.



[School of Civil and Environmental Engineering, Georgia Institute of Technology, http://www.ce.gatech.edu/].

Seismic Cone Penetrometer (SCPT Test)

A SCPT cone is additionally equipped with geophones in order to be able to perform shear wave velocity measurements (Downhole, Chapter 2.12.4).

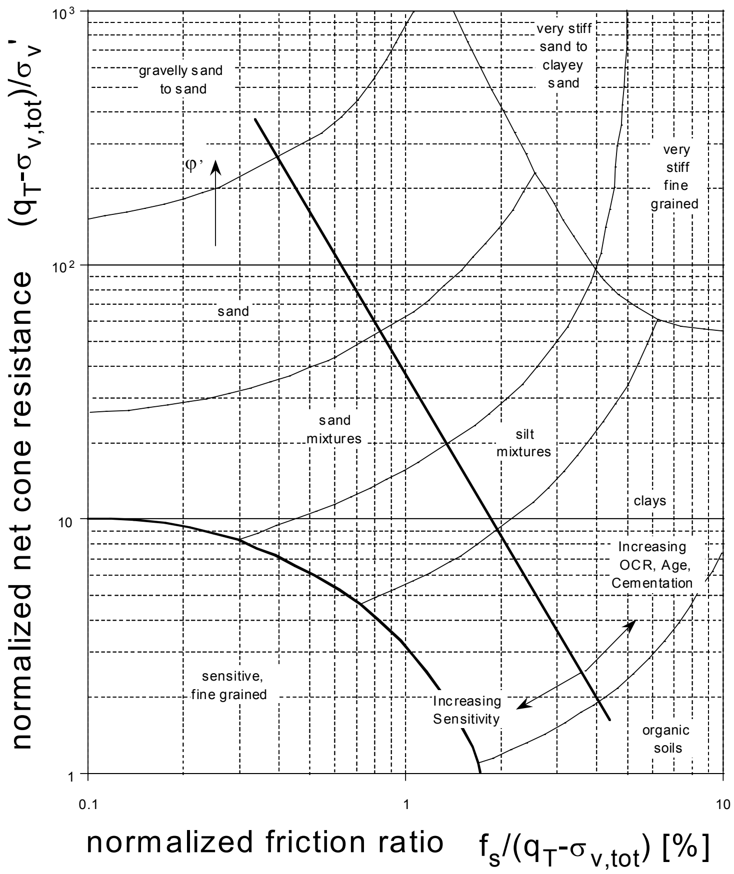
Advantages and disadvantages

Advantages: Fast method, gives good profiles, relatively cheap, a lot of correlations exist. Allows measurements at *in situ* conditions, avoiding problems relating to sample disturbance.

Disadvantages: Only usable in soft to medium stiff materials without boulders. A classical borehole is still recommended for correlations.

Evaluation techniques: soil classification

Soil profiling and classification



With the aid of above figure (based on Robertson, 1990), the soil type can be evaluated by means of the normalized friction ratio and the normalized net cone resistance.

Normalized friction ratio: $R_{fn} = \dfrac{f_s}{q_T - \sigma_{vo}} \cdot 100 \quad [\%]$

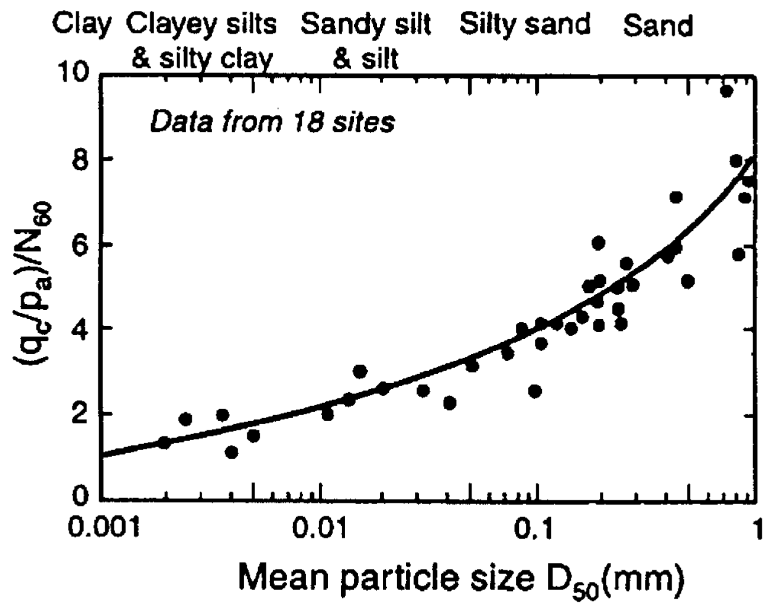
Normalized net cone resistance: $q_{Tn} = \dfrac{q_T - \sigma_{vo}}{\sigma'_{vo}}$

With σ_{v0} as the *in situ* total vertical stress and σ_{v0}' as the *in situ* effective vertical stress.

Evaluation techniques: CPT-SPT correlations

CPT-SPT correlations

The following diagram shows the CPT-SPT correlation after Robertson et al. (1983), relating the ratio $(q_c/p_a)/N_{60}$ to the mean grain size D_{50}. p_a denotes the atmospheric pressure. For fine-grained soft soils, the correlation should be applied to total cone resistance q_T.



Evaluation techniques: undrained shear strength

Evaluation of the undrained shear strength

From the bear capacity formulation for undrained conditions,

$$\sigma_f = N_c \cdot s_u + (\gamma\, t + q)$$

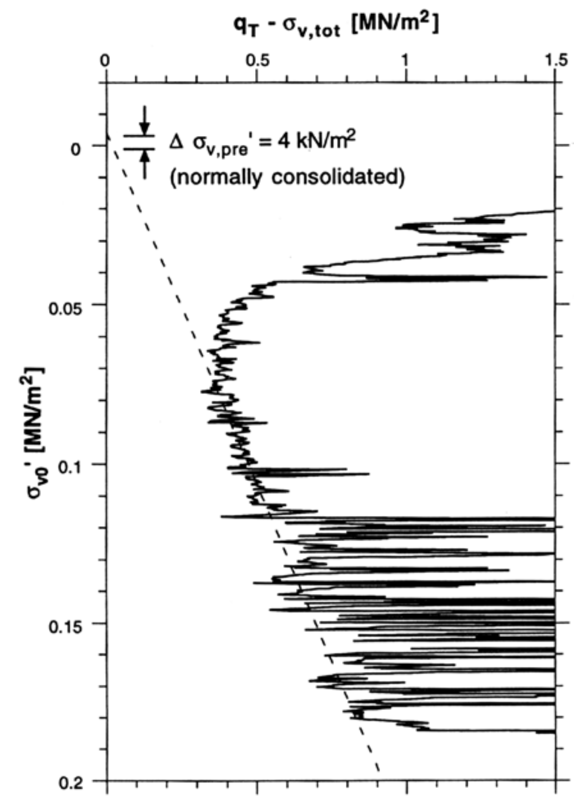
the undrained shear strength s_u for a CPTU test can be expressed as

$$s_u = \frac{q_T - \sigma_{v,tot}}{N_{KT}} = \frac{q_{T,net}}{N_{KT}}.$$

With $\sigma_{v,tot}$ as the total vertical stress and N_{KT} as the "cone factor".

The difference (q_T - $\sigma_{v,tot}$) is expressed as $q_{T,net}$ and represents the cone resistance mobilized by the undrained shear strength of the soil. The main assumption here is that s_u increases linearly with the *in situ* effective vertical stress σ_{v0}'.

The cone factor N_{KT} can be assessed by correlations with field shearing tests. The theoretic values for N_{KT} vary between 9 and 18.



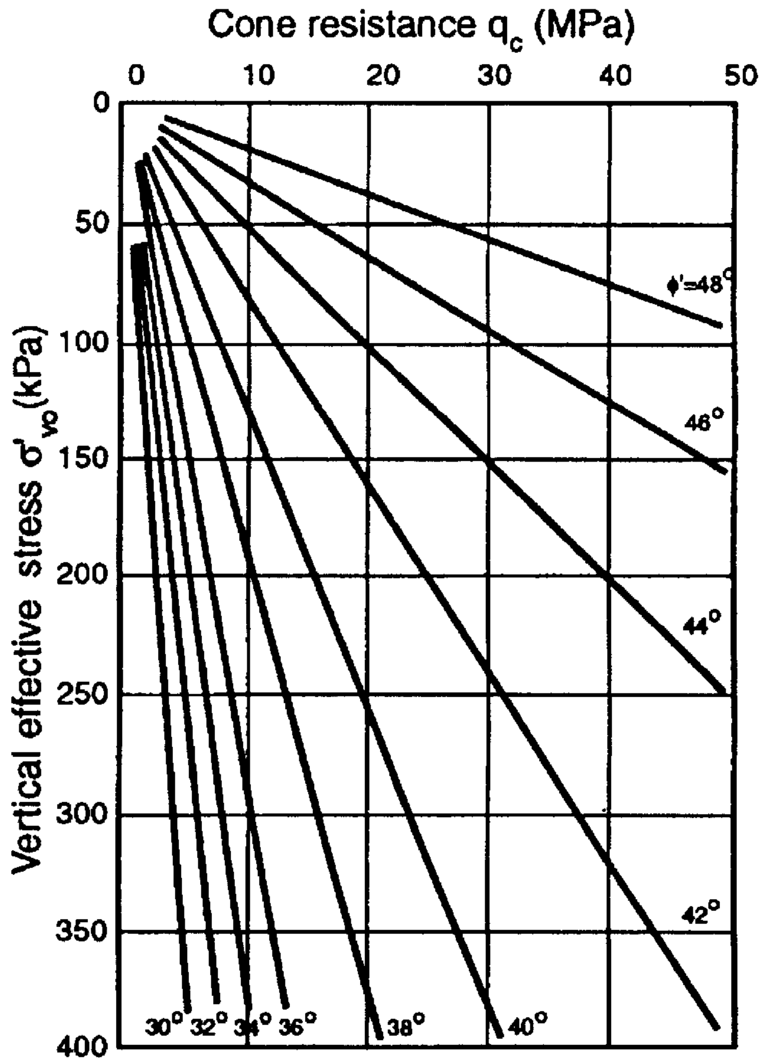
The above figure [Amann P., Heil M. (1995)] shows the linear relationship between the net cone resistance and the *in situ* effective vertical stress. With this relationship, it is also possible to estimate the pre-consolidation stress by extrapolating to negative depths.

Further Literature on CPT:

- Jamiolkowski, M., Ghionna, V., Lancellotta, R. & Pasqualini, E. (1988).
- Amann P., Heil M., Huder J. (1997).
- Mitchell J. K., Yu H. S. (1998)
- Springman S.M., Giudici Trausch J., Heil H.M., Heim R. (1999).

Evaluation techniques: Friction angle

Estimation of the peak angle of shear strength



The above figure relates the peak angle of shear strength with cone resistance q_c and vertical effective stress σ_{v0}' [Robertson, P.K. and Campanella, R.G. (1983)].

Evaluation techniques: shear wave velocity

Evaluation of shear wave velocity

The proposed correlation between shear wave velocity and cone resistance q_c is:

$$v_s = 55.3\ q_c^{0.377} \text{ (Iyisan, 1996)}$$

This correlation is valid for all soil types. The validity of the estimation of shear wave velocity using this empirical correlation must be verified by performing at least two down-hole tests in the area under analysis.

Evaluation techniques: Liquefaction potential

Evaluation of liquefaction potential

The following procedure to evaluate the liquefaction potential is recommended:

1. The *in situ* equivalent cyclic stress ratio CSR is evaluated from:

$$CSR = 0.65 \frac{a_{\max}}{g} \frac{\sigma_v}{\sigma'_v} r_d$$

where
- a_{max} = peak horizontal ground surface acceleration
- g = acceleration of gravity
- σ_v = total vertical overburden stress
- σ'_v = effective vertical overburden stress
- r_d = stress reduction factor

with r_d computed as follows:

$$r_d = 1.0 - 0.00765z \quad \text{for } z \leq 9.15\text{m}$$
$$r_d = 1.174 - 0.00267z \quad \text{for } 9.15\text{m} < z \leq 23\text{m}$$

where z is the depth below surface in meters.

2. The cone tip resistance q_c is first normalized to 100kPa (approximately 1 atm) to get the normalized cone resistance q_{c1N}:

$$q_{c1N} = C_Q (q_c / P_a)$$

where

$$C_Q = (P_a / \sigma'_v)^n$$

and where
- C_Q = normalizing factor for cone penetration resistance
- P_a = 1 atm of pressure in the same units used for σ'_v
- n = exponent that varies with soil type
- q_c = field cone penetration resistance measured at the tip

At shallow depths, C_Q becomes large because of low overburden pressure, however values > 1.7 should not be applied (Youd et al., 2001). The value of the exponent n varies from 0.5 to 1.0, depending on the grain characteristics of the soil (Olsen, 1997). An exponent n of 1.0 is the appropriate value for clayey type soils. For clean sands, an exponent of 0.5 is more appropriate, and a value intermediate between 0.5 and 1.0 would be appropriate for silts and sandy silts (Youd et al., 2001).

3. q_{c1N} is further corrected to $q_{c1N,CS}$ in order to take the influence of fines content into account:

$$q_{c1N,CS} = K_c \, q_{c1N}$$

with

$$K_c = 1.0 \quad \text{for } I_c = 1.64$$
$$K_c = -0.403 I_c^4 + 5.581 I_c^3 - 21.63 I_c^2 + 33.75 I_c - 17.88 \quad \text{for } I_c > 1.64$$

and where

$$I_c = \sqrt{(3.47 - \log Q)^2 + ((1.22 + \log F)^2}$$

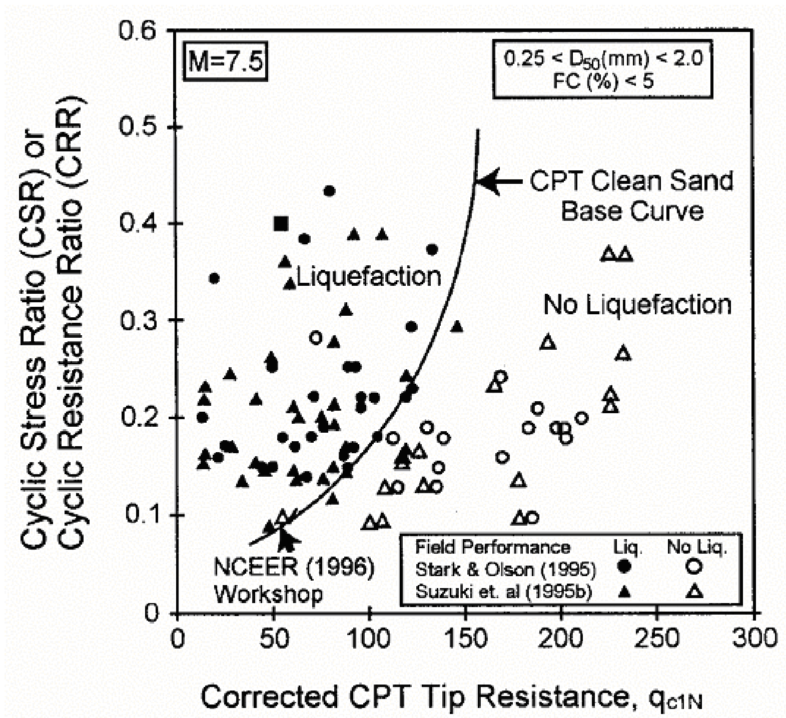
with

$$Q = \frac{q_c - \sigma_v}{P_a}\left(\frac{P_a}{\sigma'_v}\right)^n \qquad and$$

$$F = \frac{f_s}{q_c - \sigma_v} x100\%$$

with f_s as the sleeve resistance.

4. The liquefaction potential is finally evaluated with the following figure:



- The above figure is valid for magnitudes Mw of 7.5. For other Magnitudes M_w, CRR should be adjusted as for SPT tests, cf. Chapter 2.12.2.

Literature

Other basic literature on the evaluation of the liquefaction potential with CPT tests is:

- Robertson, P.K., and Campanella, R.G. (1985).
- Stark, T.D., and Olson, S.M. (1995).
- Youd, T.L., Idriss, LM., et al. (2001).

2.12.2 SPT Test

Results and presentation

Results:
- Correlations with geotechnical and geophysical properties

Short characteristics of the test procedure

Procedure:
A split-barrel sampler is driven from the bottom of a pre-bored hole into the soil by means of a 63.5kg hammer, dropped freely from a height of 0.76m. The diameter of the pre-bored hole varies normally between 60 and 200mm. If the hole does not stay open by itself, casing or drilling mud should be used. The sampler is first driven to a depth of 15cm below the bottom of the pre-bored hole, then the number of blows required to drive the sampler another 30cm into the soil, the so called N_{30} count, is recorded. The rods used for driving the sampler should have sufficient stiffness. Normally, when sampling is carried out to depths greater than around 15m, 54mm diameter rods are used.

Advantages and disadvantages

Advantages: Widely used test, with extensive available correlation databases.

Disadvantages: Gives only pointwise characteristics, not feasible in dense sand with boulders. Quality of results depends on a very careful execution. Always needs a borehole.

Minimal requirements

According to procedure defined in ASTM D 1586-84 of the American Society of Testing Materials (ASTM).

SPT Set-up	Recommended Procedure
Borehole size	66mm < Diameter < 115mm
Borehole support	Casing for full length and/or drilling mud
Drilling	Wash boring; side discharge bit Rotary boring; side or upward discharge bit Clean bottom of borehole
Sampler	Standard 51mm O.D. + 1mm 35mm I.D. + 1mm > 457mm length
Penetration Resistance	Record number of blows for each 150mm N = number of blows from 150 to 450mm penetration

Evaluation techniques: shear wave velocity

Evaluation of shear wave velocity

- For sands:
  $v_s = 57.4\ N^{0.49}$ (Lee, 1990)

- For clays:
  $v_s = 114.43\ N^{0.31}$ (Lee, 1990)

- For silts:
  $v_s = 105.64\ N^{0.32}$ (Lee, 1990)

- Valid for all soil types:
  $v_s = 51.5\ N^{0.516}$ (Iyisan, 1996)

Comment: The above correlations should be used with greatest care. The validity of the estimation of shear wave velocity using these empirical correlations must be verified by performing at least two downhole tests in the area under analysis.

Evaluation techniques: liquefaction potential

Safety factors for liquefaction (based on Youd et al., 2001)

The recommended approach adopted to calculate the safety factors with respect to liquefaction is based on the method developed by (Youd et al., 2001). The safety factors need to be determined for each representative borehole.

The basic steps to be performed are:

Step 1.

CSR (the Cyclic Stress Ratio) is calculated from Seed and Idriss (1971) as,

$$CSR = \frac{\tau_{av}}{\sigma'_v} = 0.65 \frac{a_{\max}}{g} \frac{\sigma_v}{\sigma'_v} r_d$$

where a_{max} = peak horizontal ground surface acceleration
g = acceleration of gravity
σ_v = total vertical overburden stress
σ'_v = effective vertical overburden stress
r_d = stress reduction factor.

The average values r_d is calculated by the expression

$$r_d = \frac{(1.00 - 0.4113z^{0.5} + 0.04052z + 0.001753z^{1.5})}{(1.00 - 0.4177z^{0.5} + 0.05729z - 0.006205z^{1.5} + 0.001210z^2)}$$

where z is the depth below ground surface in meters.

Step 2.

Corrected $N_{1,\,60}$ values are calculated as

$$N_{1,60} = NC_N C_R C_S C_B C_E$$

where

- N = measured standard penetration resistance,
- C_N = factor to normalize N to a common reference effective overburden stress,
- C_R = correction for rod length,
- C_S = correction for non-standardized sampler configuration,
- C_B = correction for borehole diameter,
- C_E = correction for hammer energy ratio.

C_N is calculated from Kayen et al. (1992), which limits its maximum value to 1.7,

$$C_N = \frac{2.2}{(1.2 + \sigma'_v / P_a)}$$

Recommended variation of other correction factors (Youd et al., 2001):

Energy ratio	Donut hammer	C_E	0.5-1.0
Energy ratio	Safety hammer	C_E	0.7-1.2
Energy ratio	Automatic-trip Donut type-hammer	C_E	0.8-1.3
Borehole diameter	65-115mm	C_B	1.0
Borehole diameter	150mm	C_B	1.05
Borehole diameter	200mm	C_B	1.15
Rod length	< 3m	C_R	0.75
Rod length	3-4m	C_R	0.8
Rod length	4-6m	C_R	0.85
Rod length	6-10m	C_R	0.95
Rod length	10-30m	C_R	1.0
Sampling method	Standard sampler	C_S	1.0
Sampling method	Sampler without liners	C_S	1.1-1.3

Step 3.

A further correction takes into account the influence of fines content (FC):

$$N_{1,60,CS} = \alpha + \beta N_{1,60}$$

where α and β coefficients are determined from the following relationships:

$\alpha = 0$, $\beta = 1.0$ for FC $\leq$ 5%

$\alpha = \exp\left[1.76 - (190 / FC^2)\right]$, $\beta = \left[0.99 + (FC^{1.5} / 1000)\right]$ for 5% < FC < 35%

$\alpha = 5.0$, $\beta = 1.2$ for FC $\geq$ 35%

Step 4.

The resulting $N_{1,60}$ is used with modified 5% or less fines content curve of Seed et al. (1985) to evaluate liquefaction resistance *CRR* using the equation of the curve as:

$$CRR_{7.5} = \frac{1}{34 - N_{1,60}} + \frac{N_{1,60}}{135} + \frac{50}{\left(10N_{1,60} + 45\right)^2} - \frac{1}{200}$$

Step 5.

Since the curve defined in step 4 is valid only for magnitude 7.5, a magnitude scaling factor *MSF* needs to be applied to adjust to other magnitudes (for the characteristic magnitude of 6.5 or derived by aggregation).

MSF can be chosen from:

$$10^{2.24} / M_w^{2.56} (Idriss, 1995) \leq MSF \leq \left(M_w / 7.5\right)^{-2.56} \quad \text{for } M_w < 7.5$$

$$MSF = 10^{2.24} / M_w^{2.56} (Idriss, 1995) \quad \text{for } M_w > 7.5$$

Step 6.

The factor of safety FS is finally calculated as:

$$FS = (CRR_{7.5} / CSR) MSF$$

The safety factors are calculated along the whole depth of the borehole for all liquefiable soil layers based on the available SPT-N blow counts using the surface peak ground accelerations calculated from site response analysis.

2.12.3 Cross-hole Seismic

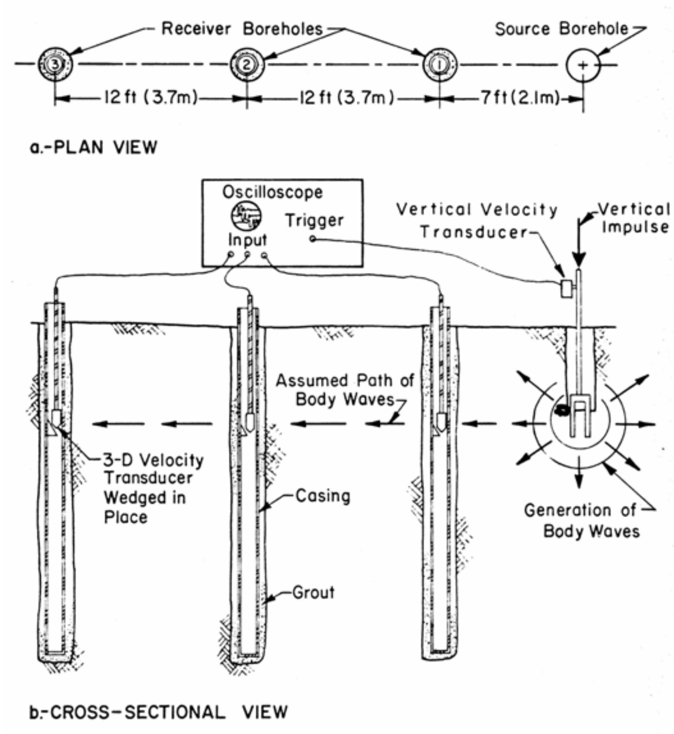
Results and presentation

Result:
Cross-hole seismic testing is used to obtain the shear wave velocity profile at a specific site. Subsequently, the elastic parameters can also be calculated.

Presentation:
Illustration of the shear wave velocity with depth.

Short characteristics of the test procedure

In cross-hole testing, the time for horizontally propagating compression (P) and shear (S) waves to travel from a source hole to a receiver hole is measured. These travel times are used to determine P and S wave velocities, which can be used to compute the elastic properties of the material. Once the vertical deviation survey is completed, the seismic source is placed in the first boring and clamped to the boring casing while generating a seismic signal. The seismic signal travels as an elastic wave to a geophone that is positioned at the same elevation in the receiver hole. The time and distance data are analyzed and interpreted to determine soil properties. With the use of vertical, radial and tangential component of the receiver, compression waves (P) as well as shear waves (SH and SV) can be measured.



Advantages and disadvantages

Advantages: Gives best results of v_s in a layer.

Disadvantages: Needs at least two and preferably three boreholes, therefore high drilling costs.

Minimal requirements

- A minimum of two borings is required ("direct travel time measurements"), but three borings are preferred and recommended ("interval travel time measurements"), since the interval travel times are normally more accurate than direct travel times.
- The spacing of the two borings should be carefully chosen: It should be large enough in order that the computation of the shear wave measurement is possible within the time resolution, but not too large in order to avoid the inclusion of more than one layer. Typically, for layered soils, the spacing can be chosen between 6 and 12m, whereas for homogeneous soils, the spacing can be increased up to about 30m. Particular care should be given to avoid errors caused by refraction in soft soils and hard bedrock (see figure below).
- The boreholes must be PVC-cased and grouted to ensure good transmission of the wave energy.
- The distance between borings at every measurement elevation must be determined precisely for subsequent velocity calculations. Since distance between borings can vary with depth due to deviation of the borehole from verticality, a borehole deviation survey is part of the cross-hole survey.
- Identification of shear wave arrival can only be achieved by using multiple pulses with different excitation directions, and signal enhancement for each direction.

Evaluation techniques

Shear wave velocity v_s is calculated as

$$v_s = \text{distance} / \text{time}$$

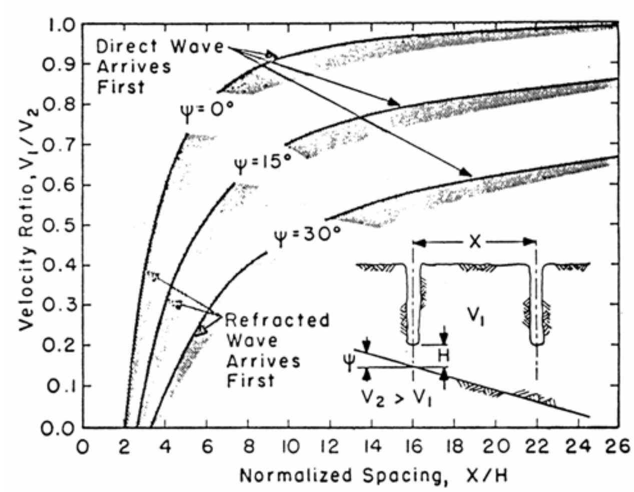
taking into consideration the corresponding travel time for horizontally propagating shear waves (SH).

Once the shear wave velocity is computed, the shear modulus can be calculated as

$$G = v_s^2 \rho$$

The accuracy of the measurement of v_s clearly plays a predominant role. A deviation of the value v_s by 10% corresponds to a deviation of the value G by 20%.

Particular attention should be paid to refracted waves. In the figure below, the arrival times of refracted and direct waves are compared.



2.12.4 Uphole and Downhole Seismic

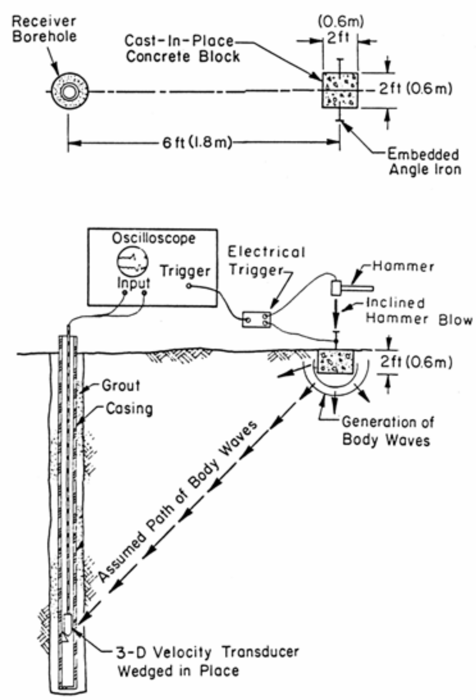
Results and presentation

Result:
Uphole and downhole seismic methods are used to obtain the shear wave velocity profile at a specific site. Subsequently, the elastic parameters can also be calculated.

Presentation:
Illustration of the shear wave velocity with depth.

Short characteristics of the test procedure

In a downhole seismic survey, a seismic source is placed on the surface near a borehole, and two geophones are placed at selected depths in the borehole.



The raw data obtained from a downhole survey are the travel times for compression and shear waves from the source to the geophones and the distance between the source and geophones. Striking a steel plate with a sledge hammer generates compression waves.

The downhole sensors consist of two triaxial geophone assemblies. Each assembly contains three sensing elements: one vertical and two orthogonal horizontal elements. A distance of five or ten feet separates the geophone assemblies. Two geophone assemblies at a fixed separation are used so that interval velocities can be determined from the same set of impulses. This method reduces timing errors caused by differences in seismic triggering and variations in source impulse characteristics.

An SCPT (Seismic Cone Penetrometer Test) combines downhole measurements with a CPTU test (2.12.1).

For an uphole test, the procedure is analogous: The source is in the borehole, whereas the receiver is at the surface.

Advantages and disadvantages

Advantages: Only one borehole needed.

Disadvantages: Not so accurate, because mainly vertical shear waves are generated, so that the shear wave velocity becomes an average over several layers and is not horizontal.

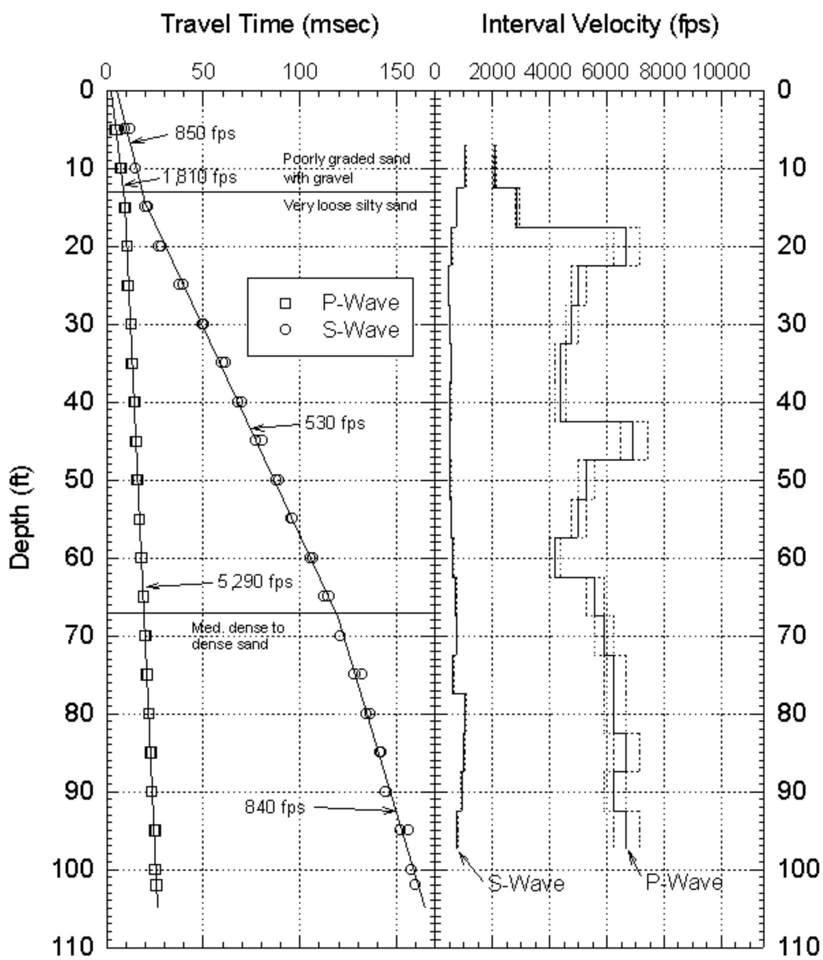
Comments: Only for verification purposes recommended.

Minimal requirements

The boreholes must be PVC-cased and grouted to ensure good transmission of the wave energy.

Evaluation techniques

The data are analyzed by determining the interval velocity for each geophone placement. Interval velocity is determined by first computing the distance from the source to each geophone and the difference in arrival times between the upper and lower geophones. The interval velocity is computed by dividing the difference in distance between the geophones by the difference in arrival times. The interval velocity is then plotted as a function of depth. Typical travel time plot and velocity profiles are shown in the figure below:



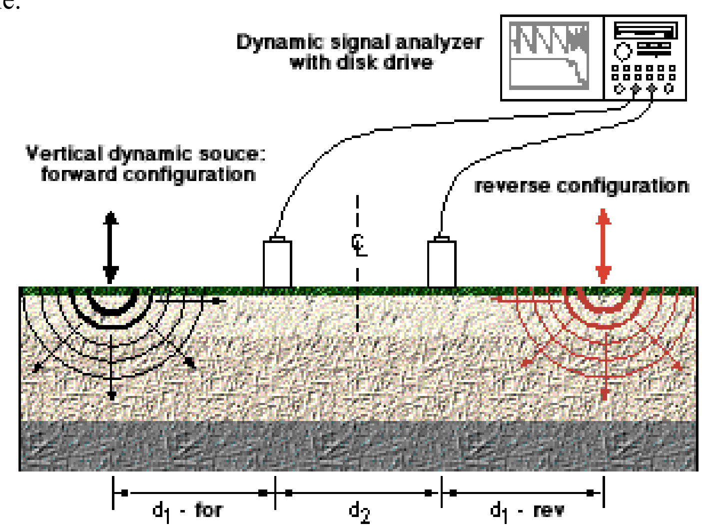
2.12.5 SASW (Spectral Analysis of Surface Waves)

Results and presentation

Result:
SASW (Spectral Analysis of Surface Waves) tests are used to obtain the shear wave velocity profile at a specific site. Subsequently, the elastic parameters can also be calculated.

Short characteristics of the test procedure

SASW testing consists of measuring the surface wave dispersion curve at the site and interpreting it to obtain the corresponding shear wave velocity profile.



Advantages and disadvantages

Advantages: Newly developed, very economical method to get shear wave profiles down to 30m. With special equipment it is applicable down to 300m. No drilling required, therefore very economical.

Disadvantages: Interpretation needs experience and special software.
Comment: In critical areas, a borehole is recommended for calibration and verification.

Minimal requirements

The equipment needed for the tests are transducers, seismometers or accelerometers, together with a two-channel data acquisition system containing frequency analyzing functions and filters.

Evaluation techniques

The SASW method consists of three stages: 1) collection of experimental data, 2) determination of the dispersion curve from the experiments and 3) inversion of the dispersion curve to obtain the soil profile.

The last step is taken by first assuming a profile and then calculating its dispersion curve and thereafter comparing the calculated curve with that of the experimental data. If there are differences, the assumed profile is modified and a new dispersion curve is calculated. The calculated dispersion curve is compared to the experimentally obtained one and so on. Today there is no direct way to invert the experimental data to provide the soil profile.

2.12.6 Microtremor measurements (Single station, Nakamura)

Results and presentation

Result:
Fundamental site period. This can be used to adjust the soil model used for amplification calculations (material properties for very small strain levels).

Short characteristics of the test procedure

Microtremors are defined as very small oscillations, which have amplitudes varying between 0.01-0.001mm and periods of 0.01-20s. The sources of microtremors can be natural and/or artificial, like wind, small magnitude earthquakes, ocean waves and/or industrial noise, traffic, etc. Microtremors are generally classified in terms of their period characteristics. Excitations with periods greater than 1s. are considered to be long period microtremors, while excitations within periods below 1s. are considered to be short period microtremors.

The single station method is based on calculation of the ratio of horizontal to vertical microtremor spectra to estimate the predominant soil period. Although the predominant frequency results deliver good agreement with detailed investigation techniques, there is no scientific consensus on the fact that the amplitude of the H/V peak is simply and directly correlated to the impedance contrast or to the site amplification, even in a relative sense. Therefore, it is recommended only to use the site frequency for verification purposes.

Advantages and Disadvantages

Advantages: This method allows adjusting the shear wave profiles derived by correlations from USCS units.

Disadvantage: Interpretation needs much experience and expertise. Good results in the case of large impedance between base rock and soft soil, but as soon as a clear impedance step does not exist, results become unreliable.

2.12.7 Array measurements

Results and presentation

Result:
Shear wave velocity profile at a specific site.

Presentation:
Illustration of the shear wave velocity with depth.

Short characteristics of the test procedure

[Fäh D., F. Kind, D. Giardini (2002)]

Noise recordings on small aperture arrays can be used, through an analysis of spatial correlation, to measure phase velocities of surface waves and invert the surface velocity structure. The array method allows for the extraction of the fundamental mode Rayleigh wave dispersion from the ambient vibration wave field recorded on a small-scale array (aperture 50-200 m) by estimation the f-k-spectrum of the wave field. The dispersion curve can then be inverted for the S-wave velocity structure. The method can be applied to any site where the wave field can be approximated as plane waves. The scheme used for the inversion of the dispersion curve in the array method is the same genetic algorithm as for the H/V ratio inversion, but the bedrock velocities are much better constrained by the dispersion curve. As with the H/V technique the inversion is not unique and several probable models result from different velocity ranges defined for the layers.

Advantages and Disadvantages

- Constraints are needed for the inversion in order to restrict the possible range of solutions.
- Since the inversion is not unique, additional information is needed in order to define the model that is most probable.
- **This method is very cost-effective, but needs extensive experience for the interpretation.**

2.12.8 Geoelectric soundings

Results and presentation

Result:
Depth of ground water table (at a point or cross-section).

Presentation:
Illustration of depth of ground water table.

Short characteristics of the test procedure

In geoelectric soundings, electrical current is applied to the ground surface through two electrodes. Additional electrodes are placed in the ground to measure variations in the potential of the electrical field that is set up within the earth by the current electrodes. The current and potential electrodes are generally arranged in a linear array. The distance between current electrodes should be three or more times the intended depth of exploration.

Advantages and Disadvantages

Advantages: Rapid, relatively cheap method.

Disadvantage: Low resolution, not suitable for detailed investigations where high precision is required.

Evaluation techniques

The apparent resistivity is the bulk average resistivity of all soils and rock influencing the flow of current. It is calculated by dividing the measured potential difference by the input current, and multiplying by a geometric factor (specific to the array being used and electrode spacing).

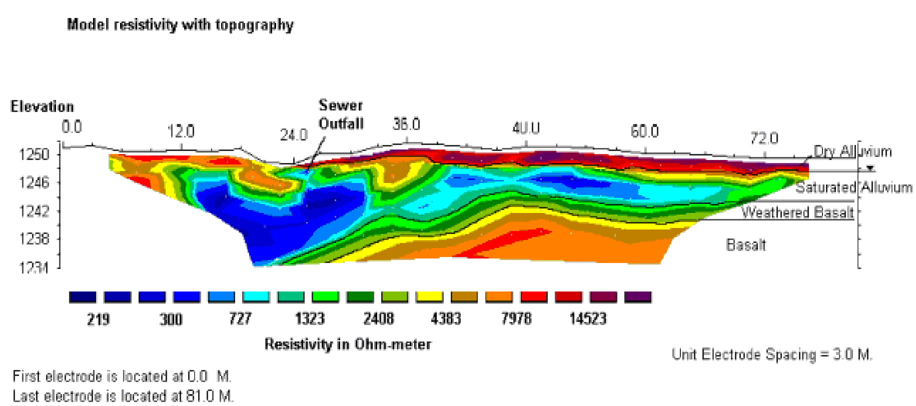


Figure R2. Example of Two-Dimensional Resistivity Profile.

[from Earth Dynamics, www.earthdyn.com]

In resistivity soundings, the distance between the current electrodes or the distance between the current and potential dipoles is expanded in a regular manner between readings, thus yielding information on the electrical properties of soils from deeper and deeper depths. Models of the variation of resistivity with depth can be obtained using model curves or forward and inverse modeling computer programs.

2.12.9 Site response analyses

Results and presentation

Input:
- Geotechnical model of soil column:
  - Depth to base rock
  - Depth to groundwater table
  - Geotechnical properties for all layers, including: thickness of layer, linear equivalent properties (shear modulus and damping as a function of shear strain), volumetric weight, maximum shear modulus or shear wave velocity, plasticity properties

    ➔ In areas with potentially dense population or hazard industries, it is recommended to establish three soil profiles to take uncertainties in the data evaluation into account. A v_s variation of +/- 30% of the "best estimate soil model" is considered reasonable. To evaluate the grid point characteristics, the resulting envelope should be taken.

Results (for both time histories):
- Output response spectra at surface

Short characteristics

The classical model is based on the propagation of shear waves in a one-dimensional column, in stratified soils.

Advantages and disadvantages

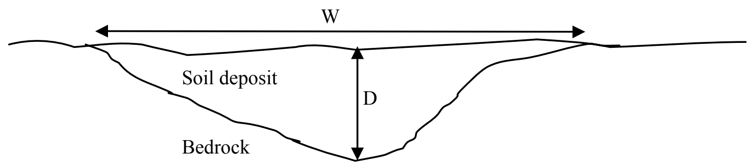
Advantages: classical, widely used method. Extensive experience in practice. Commercially available software.

Disadvantages: only feasible in more or less horizontal layered situations. The assessment of input data and interpretation of results need experience. Results from linear-equivalent models are only reliable within a limit strain level (see comments below).

Minimum requirements

One-dimensional equivalent linear site response analysis is acceptable for horizontally or nearly horizontally stratified, sufficiently homogenous soil profiles (including bedrock). In most of those cases, accurate results can be achieved, except when the modeling of the ground by a soil column is not representative. Standard programs to calculate 1D shear wave propagation of a soil column (like SHAKE, SHAKE 91 resp. ProShake, or EERA for MS Excel etc.) can be used. The criteria for the validity of these linear equivalent models should be checked according to the paragraph below (limit strain levels for calculation).

In valleys and basins, one-dimensional equivalent linear site response analysis with appropriate corrections for 2D effects and topography are recommended. Based on experience, 2D effects are only relevant in valleys where the bedrock depth D exceeds 1/5 to 1/10 of the valley width W:



Especially in basin situations, significant amplifications have to be expected at the borders. In such situations, particularly in the presence of soft soils, detailed investigations are recommended to examine the possibility of additional amplification due to 2D effects.

Particular attention should be taken when using 1D-equivalent linear analysis for very deep profiles (e.g. bedrock depth over 500m). In such cases, it is recommended to take into account the frequency dependence of both shear modulus and damping, in relation with the strain spectrum and the degradation curves.

Evaluation techniques

Calculation with program SHAKE or equivalent program (e.g. EERA for MS Excel).

The time histories calculated from the hazard at competent site conditions have to be taken at outcrop motion in the SHAKE calculation input. At each grid point, at least two different time histories should be used for the calculation to get a reasonable mean value (geometric mean) for the response spectra.

Limit strain levels for calculation

Earthquake hazard calculations for can result in quite high acceleration levels, which lead to high strain levels in the soil, causing non-linear behavior. In practice, non-linear soil behavior is taken into account by "linear-equivalent soil models". But reliable results with these models can only be achieved within an allowable strain level depending on the soil type. This allowable strain level depends on the stiffness and the strength of the soil. In general, the validity of these models ranges down to where the value of the G-modulus (dependent on the strain level according to Chapter 2.12.10) reaches a value of **half the maximum shear modulus** G_{max}.

Thus, the validity condition of the linear-equivalent soil models can be expressed as:

$$G(\gamma) < G_{max} / 2$$

Where $G(\gamma)$ is the shear modulus for the resulting strain level, and G_{max} the maximum G-modulus for very small strain.

2.12.10 Modulus reduction curves and damping

Shear Modulus Reduction Relationships, Maximum Shear Modulus

Most relationships in literature show the reduction of the normalized shear modulus as a function of the shear strain.

The maximum shear modulus G_{max} has to be assessed separately. The following relationship between G_{max} and the shear wave velocity v_s can be used for this purpose:

$$G = v_s^{\ 2}\ \rho$$

with v_s: shear wave velocity
ρ: density

Recommendations for Reduction of Shear Modulus

In absence of locally assessed reduction curves, the following relationships between shear strain γ and shear modulus G are recommended:

a) For Gravels/Sands:

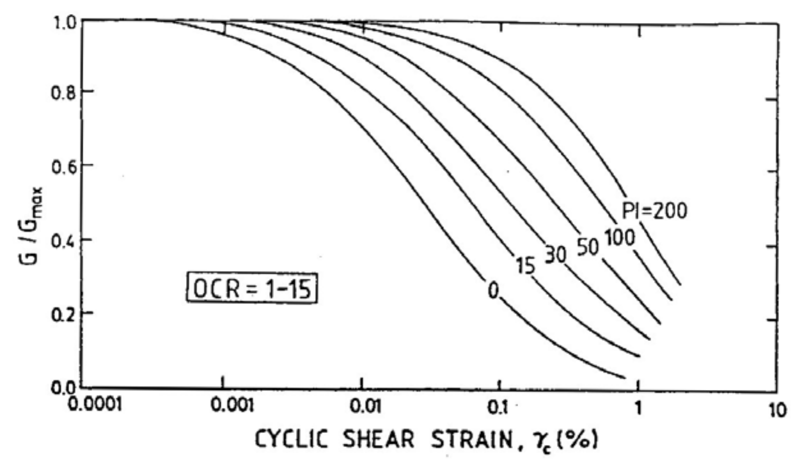
Seed et al. (1984):

$$G = 220\,K_2\,(\sigma'_m)^{0.5}\ kN/m^2$$

with $K_2 = f\,(D_R, \gamma)$ where D_R = relative density
and σ'_m mean effective main pressure in [kN/m²]

b) For Clays:

Vucetic and Dobry (1991):



The figure above shows the relationship between shear strain and shear modulus (normalized with the maximum shear modulus G_{max}), as a function of the Plasticity Index PI, valid for an overconsolidation ratio of 1 to 15.

c) For Silts:

- Silt with low plasticity behaves like fine sand, so the reduction curves for sand may be used.
- Silt with high plasticity behaves like clay, so the reduction curves for clay may be used.

Recommendations for Damping Curves

In absence of local assessed damping curves, the following relations between shear strain γ and material damping ratio λ are recommended:

For Gravel/Sands:

Hardin (1978), Hardin and Drnevich (1972):

Damping ratio: λ

$$\lambda = \frac{\lambda_{max} \cdot \frac{\gamma}{\gamma_r}}{1 + \frac{\gamma}{\gamma_r}}$$

with

$\lambda_{max} = 33 - 1.5 \log N$ for clean dry sands

$\lambda_{max} = 28 - 1.5 \log N$ for clean saturated sands

where N = number of cycles

Calculation of γ_r :

$$\gamma_r = \frac{r_{max}}{G_{max}}$$

with:

$$r_{max} = \left[\left(\frac{1 + K_0}{2} \sigma'_v \sin \varphi' + c' \cos \varphi' \right)^2 - \left(\frac{1 - K_0}{2} \sigma'_v \right)^2 \right]^{\frac{1}{2}}$$

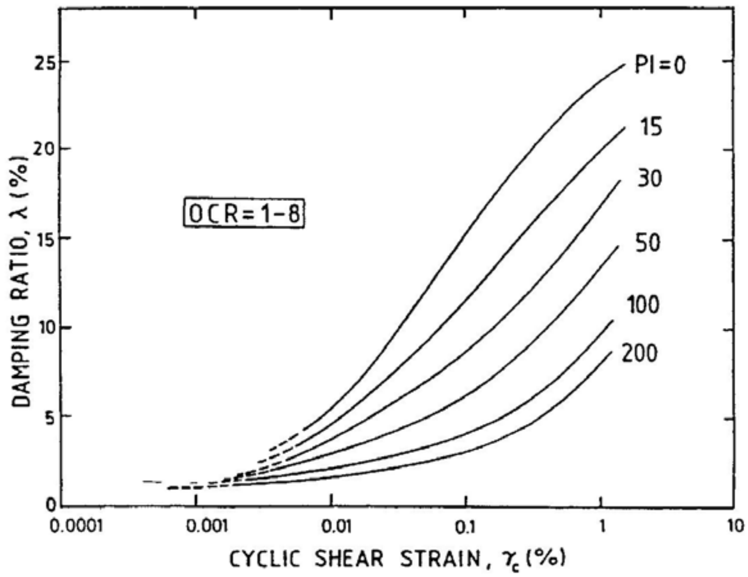
K_0 = earth pressure at rest

σ'_v = vertical effective normal pressure

φ', c' = shear strength parameters

<u>For Clays and Silts</u>:

Vucetic and Dobry (1991) and Sun et al. (1988):

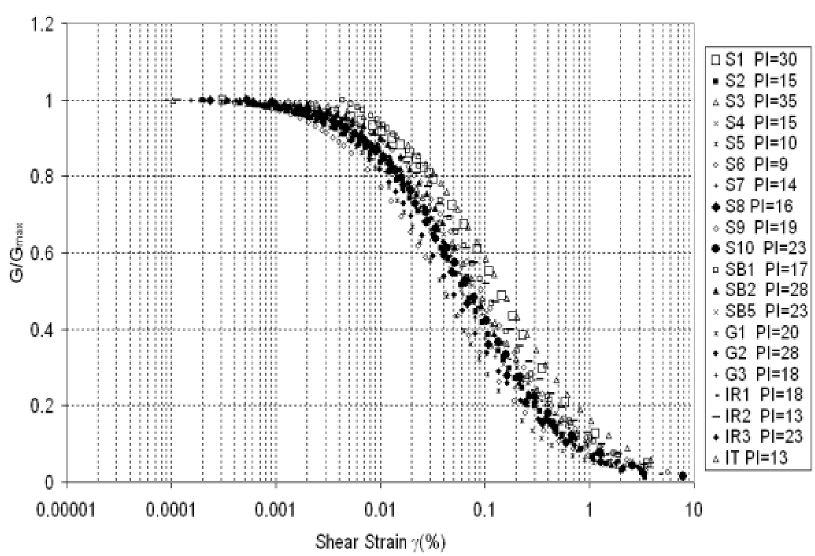


The figure above shows the relationship between shear strain and damping ratio, as a function of the Plasticity Index (PI), valid for an overconsolidation ratio of 1 to 8.

Locally Assessed Relationships

Where locally assessed relationships are available for modulus reduction or damping ratio, these relationships are conveniently used, since they reflect the real local soil conditions.

As example, a result from a study by Okur and Ansal (2001) is shown below:



Results and presentation

Result: Factor of safety at a specific point.

Short characteristics of the method

The aim of the analysis in pseudo-static conditions is the evaluation of the factor of safety (Fs) and the coefficient of critical acceleration for landslides and landslide-free areas. The critical acceleration is defined as that acceleration which when applied to the slope produces a state of incipient failure. This acceleration is assumed to be constant over the slope as if the slope is a rigid body and usually, the term refers the horizontal component of the acceleration. The factor of safety, on the other hand, is defined as the factor by how much the available strength should be reduced so that a state of incipient failure is reached. The state of incipient failure is termed the limiting equilibrium condition. Therefore the two terms, the critical acceleration and the factor of safety are both representative of the available strength in some sense. The critical acceleration is related to the load factor while the factor of safety is related to the strength factor.

Advantages and disadvantages

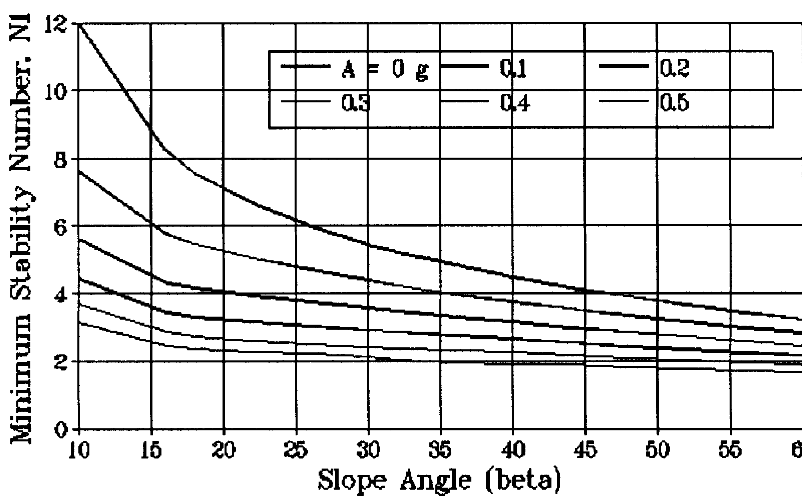
Advantages: Fast method, simple input.

Disadvantages: Real conditions are not considered in detail. Therefore, experience is needed in the assessment of representative input data.

Evaluation techniques

The method proposed defines the factor of safety in terms of the shear strength angle φ' and the stability number N_l, such that Fs = tanφ' N_l.

N_l represents the configuration of the slope and failure surface according to the following figure (Siyahi and Ansal, 1999):



with A as the peak ground acceleration in g (uppermost curve represents 0 g, lowermost curve 0.5 g) and the slope angle beta in degrees.

3. Land Use Management and Sustainable Implementation

3.1 Rationale for Municipal Land Use Management for Earthquake Safety

General

As described in Chapter 2, earthquake losses are primarily the consequence of building and infrastructure failure induced by earthquake effects. The two principal approaches to reducing these losses are to:

1. Avoid, if possible, high hazard areas for the siting of buildings and infrastructure.
2. Ensure that buildings and infrastructure are designed and constructed to resist expected earthquake loads.

The first approach of seeking safe siting is related to land use management. Mapping of the relative intensity of seismic hazards at the urban scale provides critical guidance to the urban planner, municipal officials and private builders on the safe siting of buildings and infrastructure. Determination of lands suitable for urban development in the case of municipal expansion and direction of development to relatively less hazardous areas can be an important factor in reducing earthquake losses and reducing the cost of safe construction.

The second approach to earthquake risk reduction deals with the design and construction of individual buildings. Standards for building design and construction are established in “Specification for Structures to be Built in Disaster Areas” published by the Ministry of Public Works and Settlement of the Government of Turkey. Relevant building standards for a particular structure are defined by the macroseismic zone, soil conditions at the building site and they type of construction.

Together, municipal seismic microzonation and the "Earthquake Specification for Structures" provide for both safe siting and design of urban development. The "Earthquake Specification for Structures" has been updated last in 1997. The current standards represent a generally accepted level of safety. This manual provides the state-of-the-art for seismic microzonation. These two documents must be uniformly applied in the management of development planning and the management of building design and construction to ensure future earthquake safety. Rigorous application of these tools is required for all new urban planning, development and construction. The scientific and engineering basis for these tools comes from worldwide experience of earthquake damage and extensive research.

These scientifically based tools are now available to planners, developers, designers and builders. However, their application and use must be required and enforced by municipal authorities. Implementation and enforcement of these standards by municipal authorities must be the highest priority for reducing future earthquake deaths and damage in Turkey.

Public and private loss reduction

Seismic microzonation maps provide the basis for scientifically based decision-making to reduce earthquake risk. For public agencies, private owners and the general public. The mapping of relative risk for particular earthquake effects influences public investment and development decisions to avoid areas of relatively higher earthquake hazard where possible. Earthquake risk will not in every case be the determining factor in locational or siting decisions but the existence of scientifically based microzonation maps allows seismic risk to be considered in a way that has not been possible previously.

Public sector concerns include the broad concern for the health, safety and welfare of the public and the protection of public facilities such as schools, hospitals and emergency services facilities. The public sector is also concerned with the minimization of physical and economic losses to the community. While the governorate and the central government take responsibility for emergency response and reconstruction in Turkey, it is primarily the municipality, which has responsibility for regulatory actions for mitigation or risk-reduction measures.

The private sector also benefits significantly from the application of seismic microzonation at the municipal scale. Identification of relative hazard intensity for earthquake effects such as ground shaking, liquefaction, landslide, and surface faulting provides guidance first for the avoidance of these hazard and secondly for addressing these site related hazards in specific structural design. Safe siting can reduce construction cost and loss potential.

Cost-Benefit Considerations

Both public and private building owners are concerned with the costs and benefits of earthquake mitigation measures. Efficient allocation of public and private resources requires a balance between cost of risk reduction and benefit of risk reduction. In the case of earthquake safety the benefit is measured in terms of reduction of expected loss. This requires first the estimation of expected future losses and the estimation of the effectiveness of mitigation measures in reducing those future losses. In the case of structural mitigation measures the cost is usually counted as the added design and construction costs required to provide the desired level of earthquake safety. In the case of land use mitigation measures the cost is usually counted as the opportunity cost of development at a particular site. That requires the estimation of costs associated with dislocation of activities from a particular site.

Cost-benefit analysis of earthquake safety measures is complicated by the distribution of costs and benefits. The balancing of aggregate costs and aggregate benefits may not be meaningful as the costs and benefits are not symmetrically distributed. Public sector investments in regulatory measures to reduce earthquake benefit private owners and private investments in earthquake mitigation and reduce public costs associated with disaster response and recovery.

The municipal cost of effective land use management and building regulation is generally less that 1% of building cost. The public and private benefit of earthquake loss reduction can be estimated in terms of the earthquake losses that have been experienced recently in Turkey.

Staffing and Training

Municipalities in Turkey have primary responsibility for the application and enforcement of land use and building regulations. In the case of building regulation for earthquake safety the reference standard is the "Specification for Structures to Be Built in Disaster Areas." In the case of land use management for earthquake safety the reference document is this manual.

Even the best standard is of no value if it is not properly applied and enforced. Application of seismic building and land use standards requires professional understanding and acceptance on the part of owners/developers, planners, designers and builders, policy understanding and acceptance by municipal officials elected and technical staff, and broad public understanding and acceptance of the benefit of earthquake mitigation measures.

A basic requirement for effective municipal regulation of earthquake safety is adequate and appropriately trained staff at the municipal level to interpret and apply earthquake safety standards to the planning and building process. The municipal planning staff in accordance with the procedure presented in this manual must manage the microzonation process.

3.2 Land Use and Physical Development System in Turkey

Legal components

The system of urban planning and physical development in Turkey is an agglomeration of regulations and agencies developed over decades. This system has evolved over time, starting with the ideas and practice of the provisions in the 19th century aiming to protect Istanbul and other urban areas from fires and epidemics and to maintain adequate road systems. Adoption of Roman jurisprudence in 1926 consolidated private land ownership. The Republican period addressed concerns for settling immigrants and their housing problems. Later in the 1950s attention turned to comprehensive town development and provisions for facilitating construction. The underlying policy has been the encouragement of private investments for development rather than imposing some strict control on development, and the direction of capital flow into the construction sector. The main instrument of this policy has been the 'Development Law' that regulates land use planning and building construction and is administered by the Ministry of Public Works and Settlement (MPWS). This law determines the manner physical development is to take place by means of town plans and their extensions and describes the regulation of individual buildings by means of construction and occupation permits. The 'Development Law' has been updated every 10-12 years, the most recent change taking place in 1985 with law number 3194.

DEVELOPMENT LAW (numbers in the boxes refer to articles of the existing law)

References by the Development Law to other Laws and Regulations

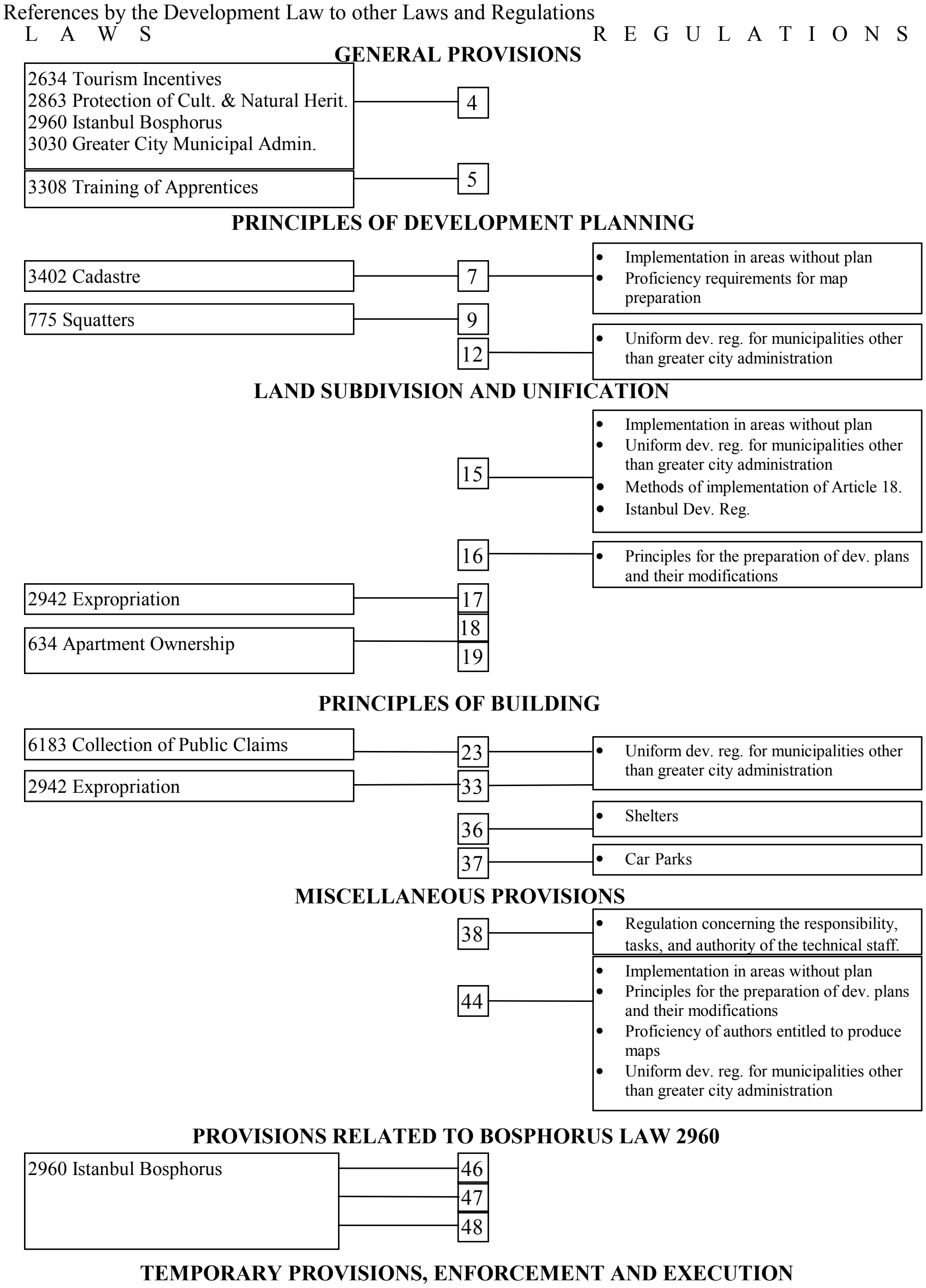


Figure 3.1: The Development Law and related laws and regulations

A major shift in policy took place with Law 3194 in 1985 with the decentralization of planning functions. This law gave the municipalities full and ultimate responsibility in preparing plans and in their ratification, free from central government control. However, the scope of all development laws has been confined to the 'physical formation' of the urban environment. Policy enforcement other than construction had to be organized under separate laws as needs arose. Thus came special laws concerning the protection of the environment, forests, sea and lake shores and rights in riparian lands, historical and natural assets, designation of special protection areas, national parks, tourism development areas, industrial development areas etc. These topic specific regulatory instruments provide the authority to prepare local plans and enforce them to many other ministries than the MPWS. Since the powers of monitoring physical development are vested in the municipalities, the MPWS has lost its direct policy control since 1985. At present, planning powers are widely diffused over various sets of regulatory mechanisms, and to various agencies in the administrative hierarchy.

The land use management system in Turkey may be outlined in terms of:

- Organizations involved,
- Powers of the central and local authorities in land use management and building construction,
- Authorities equipped with the prerogatives of development,
- Other policy instruments that contribute to activities of physical development,
- The monitoring of property rights, and
- Provisions specially devised for disasters.

Table 3.1 lists sixty-four existing and draft legal components of the conventional system concerning physical development of buildings and facilities in Turkey in seven distinct categories. The principal components for each category are briefly summarized in the following sections.

- Powers and responsibilities in the organizational structure
- Regulatory mechanisms of physical development
- Other authorities entitled with development prerogatives
- Indirect control of physical development and construction activities
- Regulations concerning real property
- Regulation of disaster management
- Changes introduced in the legal system since 1999

Table 3.1: Listing of Legal Components of the Conventional System Concerning Physical Development

1. Powers and Responsibilities in the Organizational Structure

1.1. The Law of 'Municipalities' 1580 (14.4.1930; revised by numerous laws)
1.2. The Law of 'Municipal Incomes' 2464 (29.5.1981)
1.3. The Law of 'Greater City Administrations' 3030 (9.7.1984; revised by Law: 3394)
1.4. Regulation Concerning 'Implementation of Law 3030 of Greater Cities' (12.12.1984)
1.5. The Law of 'Bank of Provinces' 4579 (23.6.1945)
1.6. The Law of 'Land Office' 1164 (10.5.1969; revised by Law: 542)
1.7. Decree Concerning 'Organization and Responsibilities of MPWS' 180 (14.12.1983; revised by decree 209)
1.8. The Law of 'Union of Chambers' 6235 (4.2.1954)
1.9. The Law of 'Engineers and Architects' 3945 (1959, 1983)

2. Regulatory Mechanisms of Physical Development

2.1. The Development Law 3194
2.1.1. Regulation on 'Uniform Development of Urban Areas' (2.11.1985)
2.1.2. Regulation on 'Principles of Preparation, Enforcement and Revision of Development Plans' (2.11.1985)
2.1.3. Regulation on 'Development in Areas where Preparation of Plans is not obligatory' (2.11.1985)
2.1.4. Regulation on 'Land Rearrangement Procedures under Article 18' (2.11.1985)
2.1.5. Regulation on 'Authors Eligible to Prepare Urban Plans' (2.11.1985)
2.1.6. Regulation on 'Authors Eligible for the Services of Map Engineering' (2.11.1985)
2.1.7. Regulation on 'Responsibilities and Liabilities of the Technical Personnel other than City Planners, Architects, and Engineers, as Referred in the Article 38 of the Development Law' (2.11.1985)
2.1.8. Regulation on 'Provision of Shelters' (25.8.1988)
2.1.9. Regulation on 'Provision of Car Parking' (2.11.1985)

3. Other Authorities Entitled with Development Prerogatives

3.1. 'Law of Promotion of Tourism' 2634 (16.3.1982; revised by Law: 3487)
3.2. 'Law of Protection of Cultural and Natural Heritage' 2863 (22.7.1983; revised by Law 3386)
3.3. 'Law of the Environment' 2872 (11.8.1983; revised by Laws: 3301, 3362, 3416)
3.4. 'Law of Forests' 6831 (8.9.1985)
3.5. 'National Parks Law' 2873 (11.8.983)
3.6. 'Law of Shores' 3621 (17.4.1990; revised by Law: 3830, Court of Constitution 1.12.1984)
3.7. 'Regulation Concerning the Implementation of Law of Shores' (3.8.1990)
3.8. 'Bosphorus Law' 2960 (22.11.1983)
3.9. 'Southeast Anatolia Regional Development Project Authority Decree' (Decree 388)
3.10. 'Privatization Law' 4046 (27.11.1994; revised by Law: 4232)

4. Indirect Control of Physical Development and Construction Activities

4.1. 'Law of Procedures to be Followed for Unauthorized Buildings in Contravention to Development and Squatters Laws and Regulations' 2981 (8.3.1984; revised by Laws: 3290, 3366)
4.2. 'Law of Squatters' 775 (30.7.1966; revised by Laws: 3016, 3414, 3811,1990)
4.3. Regulation Concerning 'Implementation of Squatters Law' (17.10.1966)
4.4. Law and Regulation of 'Public Health' (6.5.1930, revised by Law: 3572)

5. Regulations Concerning Real Property

5.1. 'Property Taxation Law' 1319 (11.8.1970; revised by Laws: 1610, 2350, 2536, 2587, 3239)
5.2. 'Apartment Ownership Law' 634 (2.7.1965; revised by Laws: 2814, 3227)
5.3. Law of 'Compulsory Purchase' 2942 (8.11.1983)
5.4. Law of 'Deeds' 2644 (29.12.1934; revised by Laws: 3278, 2421, 5520, 3000, 6217, 3678)
5.5. Law of 'Cadastral Records and Services' 3402 (9.7.1987)

Table 3.1: Listing of Legal Components of the Conventional System Concerning Physical Development (cont.)

6. Regulation of Disaster Management

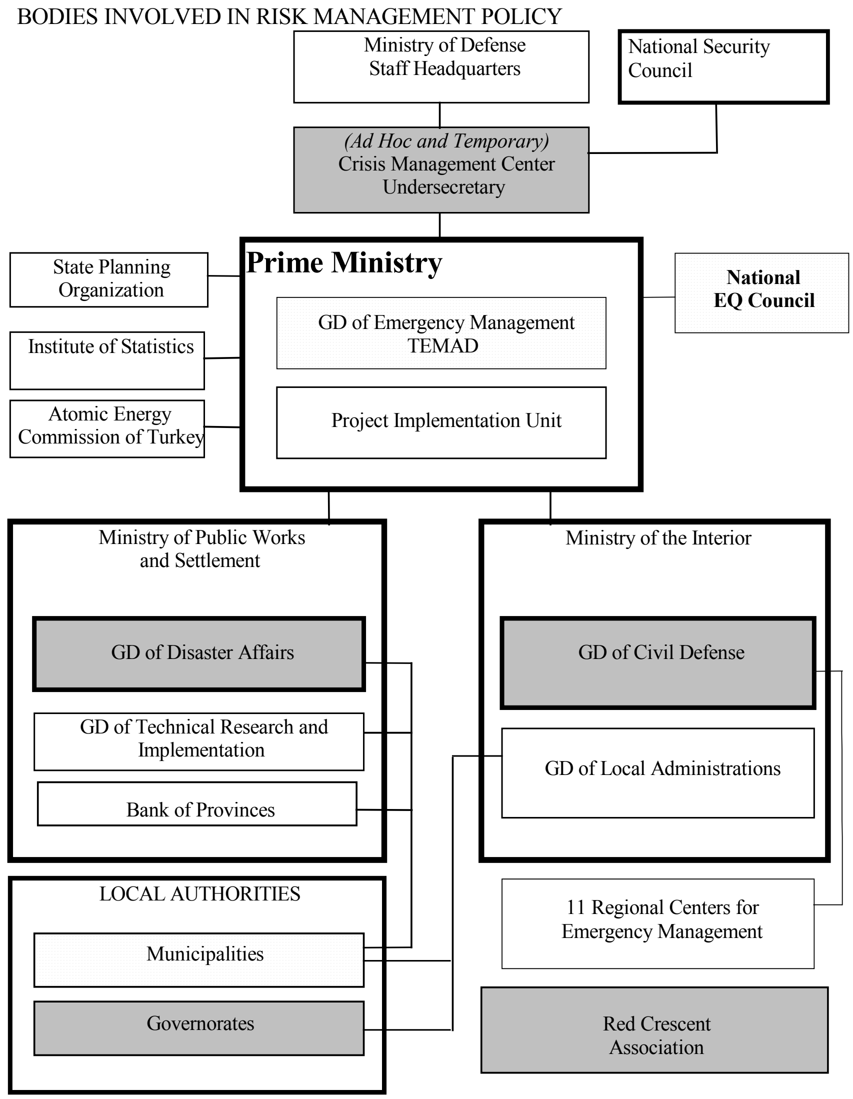
6.1. Law of 'Disasters' 7269 (25.5.1959; revised by Laws: 4123, 4133)
6.1.1. Regulation Concerning 'Building Construction in Disaster Areas' (2.9.1997)
6.1.2. Regulation Concerning 'Determination of Rights of Disaster Victims' (28.8.1968)
6.1.3. Regulation Concerning 'Discounts to be made in the Payment Programs of the Disaster Victims for Buildings Constructed by Public Means' (8.4.1972)
6.1.4. Regulation Concerning 'Principles of Distribution of the Residual Buildings and Property' (13.10.1985)
6.1.5. Regulation Concerning 'Expenditures from the Disasters Fund' (12.6.1970)
6.1.6. Regulation Concerning 'Principles in the Determination of Effects of Disasters on Social Life' (21.9.1968)
6.1.7. Regulation Concerning 'Emergency Relief Aid and Operations, and Preparation of Management Brief' (8.5.1988)
6.1.8. MPWS Mandate Concerning the 'Preparation of Geological and Geotechnical Analysis Reports for Settlement Purposes' (17.8.1987, no. 1634; repeated 31.5.1989)
6.2. Mandate of MPWS on 'Procedures for Municipalities with Infrastructural and Income Loss'
6.3. The Law of 'Protection from Floods and Inundations' 4373 (14.1.1943; revised by Law 7269, Constitutional Court Decision: 1969/70)
6.4. 'The Civil Defense Law' 7126 (9.6.1958: revised by Laws: 85, 107, 139, 219, 655)

7. Changes Introduced in the Legal System Since 1999

7.1. Organizational Changes
7.1.1. Directorates of Civil Defense for Rescue and Emergency Attached to the Ministry of the Interior (Decree 586 and 596; 27.12.1999 and 28.4.2000)
7.1.2. General Directory of Emergency Management attached to the Prime Ministry (Decree 583; 22.11.1999)
7.1.3. The independent National Earthquake Council (Prime Ministry Mandate 2000/9; 21.3.2000)
7.2. New Legal Provisions (Decrees, Laws and Mandates)
7.2.1. Decree on Obligatory Earthquake Insurance (587; 27.12.1999)
7.2.2. Decree on Construction Supervision (595; 10.4.2000)
7.2.2.1. Regulation Concerning the 'Principles of Building Supervision' (12.8.2001)
7.2.3. Decree on Proficiency in Constructional Professions (601; 28.6.2000)
7.2.4. MPWS General Directorate of Disaster Affairs Mandate (10; 15.10.1999)
7.3. The Building Supervision Law and the Draft Laws
7.3.1. The Building Supervision Law
7.3.2. Draft Law of 'Compulsory Earthquake Insurance'
7.3.3. Draft Law of 'Urbanization and Development'
7.3.4. Draft Law of 'Disasters'

Powers and Responsibilities in the Organizational Structure

The primary actors of the system of development in Turkey are the central and local public authorities (the Ministry of Public Works and Settlement (MPWS), and municipalities), the semi-official organizations and institutions (professional chambers, cooperatives, consultant firms, supervision firms, etc.), the judicial system, and the market agents (consumer households, property owners, contractors, professional individuals, etc).



<> Shaded boxes indicate responsibilities related to post-disaster activities.
<> Dotted boxes and lines indicate bodies and relations established after the 1999 earthquakes.
<> Textured boxes indicate bodies involved with (voluntary) mitigation concerns.
<> GD for 'General Directorate'

Figure 3.2: Bodies Involved in Risk Management Policy

Under the Law of **'Municipalities'** 1580 (14.4.1930; revised numerous times), municipalities are specifically responsible for the management of settlements and meeting the common needs of the citizens. The Law describes (article 7) the procedures for extending municipal boundaries by annexing developed or vacant land subject to the approval of MBWS and the Ministry of the Interior. Neither the Law nor the criteria for approval areas address the issue of development control in high hazard areas.
Article 15 of the Law of Municipalities describes the tasks of the municipal

administration. Among those are the powers of construction control and permission for building repairs. Municipalities are specifically obliged to avoid unauthorized development and remove all buildings that are unsafe and a source of potential harm. This provision should be extended to include the promotion of mitigation work in public and private buildings. Municipalities are also held responsible in the Law for taking all measures against fires. This article should be restated to cover the management of flood risks and to clarify the contemporary mitigation responsibilities of municipalities in a comprehensive manner.

Municipal police functions are explained in articles 103-106 of the Law, in the daily management of the city. Although municipalities have authority to issue penalties (article 113), unauthorized development that constitutes a public nuisance and unacceptable vulnerability to natural hazards and fire are not targeted. This could be overcome with specific inclusion of police powers for mitigation control.

Municipalities are obliged to cooperate with the central administration in issues of public health (article 158). Unfortunately the public health and welfare effects of natural disasters are not addressed and municipalities are not held accountable in fulfilling mitigation planning and control related to natural hazards.

Regulatory Mechanisms of Physical Development

The regulation of physical development in Turkey occurs on three distinct levels. The greater (metropolitan municipalities) cities (Adana, Ankara, Antalya, Bursa, Eskisehir, Gaziantep, Istanbul, Izmir, Kayseri, Konya) are, according to Law 3030, responsible for monitoring development within their borders, and enabled to develop their own regulations. The second level of development control applies to all other municipalities (and local governorates) where development is regulated by Development Law 3194 and its attendant regulations which cover the regulations and procedures of preparation of plans, and permits given to private construction and use of buildings. A third level of development control is maintained by one of the regulations of the Development Law in rural areas where preparation of plans is not a requirement.

At the second level, the ‘Uniform Development Regulation’ is provided by the Ministry for all cities other than greater (metropolitan) cities with little option for them to modify the contents. This regulation covers in essence all construction activities in urban areas in Turkey.

Unless individual municipal plans indicate specific exception, provisions of this regulation will determine development. A standard approach to development procedure and form is described throughout the regulation without allowance for the designation of zones with alternative forms and procedures of physical development. Article 5 of the Law confirms that the provisions of the ‘Specification for Structures to be Built in Disaster Areas’ of the Disasters Law (7269). Municipalities are allowed to add further conditions so long as these do not contradict the provisions of the Development Law and of this specification.

It is not permitted to improve or retrofit unauthorized buildings unless they are fully brought into conformance with the provisions of the Development Law and this specification for structures.

Each municipality is obliged to hire the services of the appropriate number of qualified planners relative to the size of its population, or have personnel of the same caliber at its own offices. The municipality is expected to judge the technical adequacy of the plans on following grounds:

- Integrity with higher level plan decisions
- Consideration of natural constraints
- Socio-economic viability
- Compatibility of land use decisions
- Feasibility of the plan
- Applicability of the plan

Municipalities are, in some cases, not capable of carrying out such technical supervision since often they are not equipped with the necessary technical expertise. In the absence of appropriate technical support, regulatory decisions may be subject to inappropriate political influence.

The current Development Law (1985) is the fourth generation in a tradition of such legislation in Turkey. The Law provides for regulating the 'appropriate formation of settlements and buildings.' However, the monitoring of development concentrates only on the construction stage and is directed only at the structural characteristics of individual buildings. The Law does not provide an incisive tool to manipulate or physically rearrange properties for purposes of 'public good' or safety in disaster-prone areas.

The Development Law does not address the organizational and entrepreneurial stages of development. It does not cover the procurement of investment, land assembly or provision of infrastructure and urban services. Furthermore, the Law does not elaborate the technical means of control during the construction stage or property management approaches to ensure safety, and it does not address issues of environmental protection. By contemporary criteria the Law is limited in its scope.

According to the Law, municipal and provincial administrations are required to prepare urban plans. Municipalities carry out this urban master planning function with very limited technical guidance or review. This Manual provides necessary technical guidance for the specific function of seismic microzonation for the inclusion of urban earthquake risk reduction measures in the master planning activity. Master Plans for urban areas represent an intermediate step in the hierarchy of physical plans. The higher and lower level plans and their relation to municipal urban master plans remain as missing links in the overall system. Urban master plans and procedures for their revisions are the primary focus of the existing spectrum of planning activities. Regional strategy plans and environmental remain undeveloped. The MPWS can prepare regional-scale plans and intervene in the preparation of urban plans where national concerns such as earthquake safety are involved, or if acute conflicts arise between local authorities (article 9). An integrated hierarchical system of plan categories and plans guiding and binding the lower and more detailed ones, and making references to higher level plans is not a requirement in the current planning practice of Turkey.

Because all powers of planning and ratification have been simultaneously delegated to local authorities, irrespective of their size and capacities, the municipal level becomes the critical focus of attention for earthquake risk reduction and mitigation implementation. The traditional centralized authority of the MPWS has been dispensed with in the Development Law number 3194 (1985). Since then, municipalities and provincial governments have been principally responsible for planning and development control functions. The dispersion of such prerogatives has led to significant unevenness in environmental standards and quality across the country.

The planning system in Turkey with its numerous regulatory mechanisms and agencies is not a unified, coherent body, and it lacks a necessary coordinated authority in monitoring physical development. There are almost a dozen public authorities and ministries other than the MPWS, which have assumed rights and powers of planning and self-approval for various special topics. It is often difficult to settle disputes as to which authority has the ultimate authority at a specific location. This ambiguity has direct implications for disaster policy. Since the overall planning control is diffused, it is difficult to consistently follow the principles of risk reduction.

Aside from the multiplicity of planning and self-ratifying bodies and the unaccountable development practices of the local authorities, no effective legal liability has been institutionalized in relation to the production of buildings. Building production as part of the Development Law is carried out with limited supervision in practice. Necessary expertise for project plan review and on-site inspection in the process of production is not provided in the system. Any university graduate can become a member of a professional chamber and, with no further examination or certification, is entitled to assume responsibilities for project design and implementation. The Law does not specify the various responsibilities of public officials or building professionals in the process of producing buildings, and the penalties described for non-conforming activity are not effectively enforced. A system that does not provide effective mechanisms for the supervision of development and building production falls short on enforcing safety standards and generates settlements vulnerable to hazards, including earthquake. The Ministry of the Interior and the Ministry of Public Works and Settlements represent a special case in the supervision of local authorities. The former has direct authority over the actions of local authorities but has no technical capacity to direct the inspection of plans and projects. The latter, on the other hand, has capability for support of technical inspection but lacks necessary authority over the local authorities. Thus the responsibilities of enforcing the Development Law (by MPWS), implementing the provisions of the Law (by municipalities), and powers of control (by Ministry of the Interior) are unfortunately distributed between three entities which lack clear focus on the priority of disaster risk reduction.

According to the Development Law, responsibilities for all planning and building supervision are part of the tasks of the municipalities for areas within their jurisdictional borders, and of the provincial governors (in all areas external to the municipal boundaries). Local authorities are entitled and responsible for the technical control of projects as well as of their implementation. For the most part, local authorities are in no position to carry out such control functions because their financial and technical manpower capacities are considerably smaller than the tasks require. Building control is therefore almost non-existent in the system, despite the provisions of the Law. In all construction work, ‘building control’ is supposed to be carried out by a ‘professional with technical liability.’ The fact that this building control professional is hired by the owner or the developer creates a significant conflict of interest. As if to complement this condition, the municipalities are not effectively held liable for omission of responsibilities for development and building control. This situation has been aggravated by the fact that no legal measures have been taken against officials failing to perform their duties as described in the Law. However, following recent major earthquake disasters the public has recognized the consequences of failures in the building regulatory system. Both legal liability and personal and professional moral responsibility demand diligence in the development and building regulatory system.

Required building permits can only be granted on the basis of project plan review. Projects submitted to the local authorities are required to meet the requirements of both the 'building' and 'disaster' regulations. Building regulations of the Development Law comprise dimensional standards, requirements for heating, lighting, landscaping, parking, fire regulations, etc. Several of these regulations refer to the 'Regulation Concerning Structural Safety Standards in Buildings' of the Disaster Law. It is only after verifying conformity with the Law and its regulations, that the local authorities are authorized to issue a 'building permit' for any project. Plans are usually checked by municipal officers in terms of physical dimensions only. Structural safety and the calculations and drawings of the engineer are seldom scrutinized. There is a series of approvals to be obtained during the process of building construction, each corresponding to some site inspection and fees to be paid. Following the construction activity, a 'use-permit' is issued to verify that all was built as planned. A use-permit is necessary for occupation and connection of urban services. In this case, a site inspection is necessary to establish that the building has appropriately conformed to the approved project plan. The plan review and inspection process must be more rigorous to include inspection at key stages during construction to check and enforce structural conformity with approved plans.

Insufficiently qualified individuals who are directly paid by the contractor often undertake the technical inspection of on-site building activities. Such external services are no substitutes for formal inspection with legal liability. The function remains a legal responsibility of the local authorities and should not be delegated. The regulation that buildings will not be allowed to have access to service networks of electricity, water and sewage discharge systems unless they obtain a 'use-permit' must be enforced rigorously.

Land Use Management

Land assembly and preparation, sub-division procedures, provision of infrastructure, and re-arrangement of property rights are the powerful prerogatives of the municipality. These are applicable particularly in areas where rural to urban conversions take place. For any particular site, such powers are effective at only one point in its development history. At that point of conversion from 'undeveloped' to 'potential development' status, land is assumed to gain greater value. For this reason, land is subject to compulsory public acquisition (*eminent domain),* up to 35% of its undeveloped surface area as a public 'development share,' according to the article 18 of the Development Law. These powers at the point of conversion and extension of municipal boundaries are the only operational tools and control procedures for land use planning provided within the articles of the Law. For this reason, the Development Law recognizes only two types of zones, and the Law in total is geared towards the one-way transformation process of urban growth. Apart from 'non-developable' and 'developable' lands, no other zones are designated. 'Zoning' in this sense refers to the delineation of land and its long-term designation to some purpose under a specific authority and distinct regime by law, rather than a simple description of uses by means of a legend or explanatory notes of a specific plan.

Disaster mitigation measures in land use planning and in building construction remain external to the conventional system of the Development Law. Absence of reference to disaster risk management in the main body of the Development Law is a conspicuous omission because land use management based on microzonation provides a critical tool for earthquake risk reduction. Land-use planning and zoning, transportation and infrastructure planning, procedures for density assignment, planning of open-spaces, participation processes, strengthening and devising of new methods of monitoring building use, *etc.* are all distinct aspects of disaster mitigation that need be covered in the De-are all distinct aspects of disaster mitigation that need be covered in the Development Law. The most efficient and cost-effective opportunities for earthquake loss reduction exist in the process of land development and new construction. Disaster risk reduction must be addressed in the legal and organizational system of physical development. Standards for land use management as well as building construction are essential elements of development policy.

The narrow scope of the Development Law and its limited implementation gave rise to separate laws for specific regulatory needs in the physical environment, as in the case of special areas like 'shore areas', 'areas of historical and natural significance', 'metropolitan areas', 'tourism centers', 'national parks and reserves', and 'areas of ecological significance'. These have all been singled out as special cases and covered under distinct laws and assigned to separate authorities.

Apart from the powers of *eminent domain* and that of imposing shared-easements (article 18, applicable only at urban fringe areas subject to development), there are no effective tools in the planning repertoire for hazard zonation. Much is necessary, however, in a system of mitigation, in efficiently avoiding building on areas of high hazard potential, improving the building and environmental standards in existing built-up areas, avoiding multiple disasters by strict use control, *etc*., all of which require more incisive tools. Disaster management is an area of activity in which a legitimate case for levying more strict planning control could be made. It is of critical importance to make full use of the currently available legal authority and the currently available tools such as seismic microzonation to introduce appropriate mitigation measures in the development process.

Other Authorities Entitled with Development Prerogatives

The **'Law of Promotion of Tourism'** provides the principles for planning and construction activities within the designated centers of tourism. Locations and boundaries of tourism attraction areas are determined with the collaboration of the Ministry of Tourism and the MPWS. A commission formed by the representatives of State Planning Organization and nine other ministries then review such joint proposals. The proposition is then submitted to the Board of Ministers.

Laws providing special authorities include the 'Law of Protection of Cultural and Natural Heritage', the 'Law of the Environment', the 'Law of Forests', the 'National Parks Law', and the 'Law of Shores', among others. The interests of these special authorities often coincide with the interest of disaster risk management. For example, environmentally sensitive lands may also be subject to landslide or liquefaction providing a stronger argument for preservation of open land and restriction on development.

Indirect Control of Physical Development and Construction Activities

Under the Law of **'Squatters'**, which regulates illegal housing areas in Turkey, three types of operations are envisaged: removal, improvement, and prevention of sub-standard housing. Since 1985 the implementation of this law has been the responsibility of the municipalities. This law offers a further potential opportunity for the application of seismic microzonation to risk reduction.

The Squatters Law contains as a real clearance mechanism, elements and tools that could be modified and applied in the renovation and clearance of areas likely to experience elevated earthquake hazards. It may also serve as a model for mitigation programs directed toward relocating or upgrading of existing settlements in hazardous area.

Regulations Concerning Real Property

Under the Law of **'Property Taxation'**, local authorities are entitled to be the beneficiaries and accountants of the property tax levied differentially in three forms of property identified as buildings, building plots and land. The Law defines 'taxable value', 'tax rate', parties liable, exemptions and cases excused.

The Law allows total exemption for five years of property in disaster areas, and ten years for new constructions in such areas. An extension of this approach to provide incentive for implementation of mitigation measures could be the empowerment of the Development Regulations and Application Plan making of municipalities to apply risk-based tax rates with ± 0.25 variations based on site hazard or conforming to safety standards.

Although the procedures and principles determined by Law, the local authorities are capable of determining the base values of land for each locality upon which the taxable values of property are calculated. This leads to the preparation of 'tax maps' of cities managed by the municipalities. There may be a scope here to incorporate in such maps consideration of earthquake risk associated with particular site. Using seismic microzonation maps to define zones of relative hazard level, differential, risk-based land tax rates could provide incentive for avoiding high hazard areas for development investment.

Regulation of Disaster Management

Disaster management policy includes the regulations and institutions related to the physical development and land use issues of 'disaster mitigation, as well as official and non-official bodies related to 'emergencies and rehabilitation.' As described above, disaster policy in Turkey is shaped in legal and organizational terms, by the 'Development Law' (1985) and the 'Disasters Law' (1959) together with their attendant regulations. The chart (Figure 3.3) below presents the structure of conventional elements of disasters policy in Turkey, the changes that occurred after 1999, as well as current attempts aiming to shape the near future.

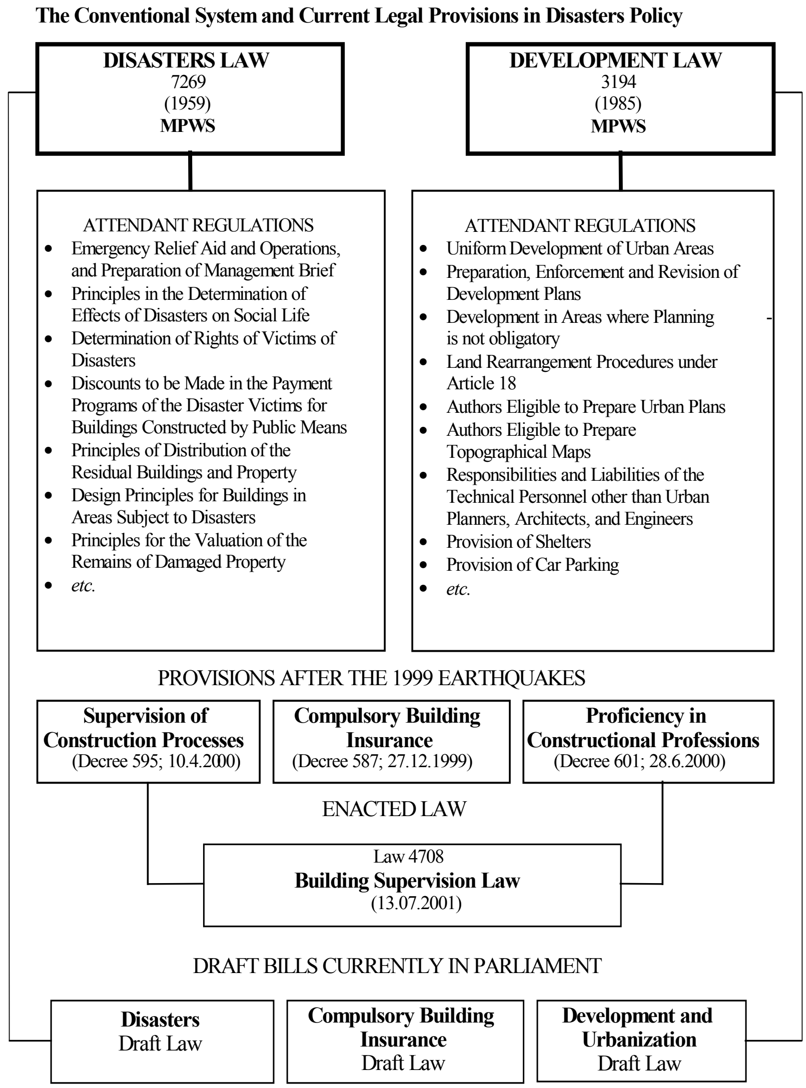


Figure 3.3: Conventional Elements of Disaster Policy

The Law of **'Disasters'** encompasses the following specific provisions:

(a) Definition of Disaster and the Declaration of a Disaster: A disaster is defined in terms of the size of a settlement, the number of dwellings destroyed, or the volume of damages experienced in agricultural crops. The assumption is that there are critical thresholds beyond which the collective life is affected by such external events. In the declaration of a national disaster, social and economic nature of the settlement, and the public response levels are also taken into account (article 1).

(b) Indication of Potential Disaster Areas on Maps and Urban Plans: The MPWS is to determine areas and settlements of potential earthquake hazards and indicate 'areas subject to disasters' on urban plans and maps and have the approval of the Board of Ministers. Areas of potential flooding on the other hand, upon the proposition of the MPWS, is to be prepared by the Ministry and the State Administration of Water Works. (Article 2). This Seismic Microzonation Manual, which has been developed by the General Directorate of Disaster Affairs of MPWS, defines the scientific procedure for the preparation and interpretation of urban scale maps of potential earthquake hazards. It is now the job of the planning departments of the municipalities to develop and apply seismic microzonation in their urban master planning and to the control of land development and building.

(c) Reconstruction Responsibilities in Disaster Areas: The MPWS has powers to stop all constructional activities after a disaster, or allow the municipality to provide construction permits, or carry out supervision functions of existing buildings and construction activities (article 3). The post-earthquake period is a critical time for application of seismic microzonation. Reconstruction and new development must be directed to safer sites wherever possible.

(d) Emergency Preparedness and Coordination: Provincial governorates and the MPWS have to maintain cooperation in the preparation plans for emergency services. Plans are prepared by each governor with detailed specifications of duties and responsible individuals of nine broad types of tasks. In the provincial and sub-provincial centers are extra-ordinary powers in the event of a disaster (articles 4, 6). The governor, including the military and the Red Crescent, conducts all administrations and local powers. Committees formed are responsible for the identification of damaged buildings in three categories: heavily damaged, medium, and those with minor damages. Those to be taken down, debris removal, construction ban, permissions for the reconstruction or retrofitting of less damaged buildings will be determined by the same committee (articles 13-14). Buildings in contravention to decisions are pulled down. While provincial governorates are in charge of emergency preparedness, the availability of municipal seismic microzonation maps provide a critical input to the estimation of future damage and the planning for future disaster response.

(e) The Need to Revise the Urban Plans: The MPWS is entitled to and responsible for the revision of development plans of settlements that experienced disasters within 5 months, if deemed necessary. If not, granting of construction permits should be allowed. Articles 16-32 of the Law determine in detail the procedures for recording of the state of damages in buildings, their values and owners to be entitled to a new dwelling; the determination of safe areas for new development, immediate mapping and geological investigation of such areas, expropriation, preparation of urban plans and infrastructure projects, and arranging constructional activities; distribution of credits, plots or dwellings to individuals, and their debt repayment programs. Revised master plans following earthquakes must reflect state-of-the-art seismic microzonation.

(f) Individuals Entitled to Aid: The Law gives the responsibility of providing decent homes for the disaster victims who have lost their homes to the MPWS. This obligation is the major source of public expenses together with infrastructural investments after major earthquakes. Housing planned and constructed by the MPWS is transferred to the entitled individuals on long-term no-interest basis. The infrastructure and land costs are not transferred to those entitled in their debt programs (articles 26-29). If the victim's dwelling was insured, the insurance payments are deduced from the aids made (article 29). Location of replacement housing districts must be guided by site hazard assessments from scientifically based seismic microzonation maps.

(g) Resources for Disasters: A fund has been established which receives contributions from: allocations made by the MPWS, 3% of annual profits of State Enterprises, donations, return flows of debts, etc. (article 33). In extra-ordinary cases, the MPWS is entitled to borrow up to 3 years of its likely budgets, allocated by the Ministry of Finance (articles 34-35). The outflows are those of rehabilitation costs for infrastructure, surveying, mapping and preparation of plans, research, housing and other forms of rehabilitation aids (article 36).

(h) Forms of Aid: Property in the form of plots or dwellings is allocated to those entitled, as no-interest long-term (20-30 years) mortgage debts (article 40). If debts are cleared before termination of program envisaged, a 10% discount is made on the remainder debt. Postponements are subject to 5% increase. Property could not be transferred to others before all debts are cleared. The debts in many occasions could be reduced by 50%; other public debts of the beneficiaries could also be postponed.

(i) Privileges and Penalties: The Disasters Fund is not liable to taxation and is not obliged to follow the Law of Public Tenders (article 43-46). Other privileges are provided in imports, transportation, forestry products, and construction materials. Donations made to the Fund could be accounted as costs for the real and institutional persons and firms. Ignoring or avoiding the tasks given by the governors during the emergency periods could bring fines to individuals.

Changes Introduced in the Legal System Since 1999

A revitalization in the existing agencies responsible for natural disasters did take place after the 1999 earthquakes. With a reframed approach to disasters and determination not to exclude mitigation measures, the government envisaged the establishment of new and complementary units. The events gave great impetus to the existing organizations, in the re-evaluation of their own capabilities, and in devising more efficient methods of carrying out their tasks. Besides reviewing the effectiveness of the two existing official institutions directly related with earthquakes (the General Directory of Disaster Affairs of the MPWS, and the General Directory of Civil Defense of the Ministry of the Interior), new organizational steps were taken in several directions. In the first place, responsibilities of the local authorities were extended to cover disaster mitigation efforts by the Decrees of the Board of Ministers and by amendments to the existing Law of Municipalities (1580) and the Civil Defense Law (7126).

In organizational terms, several efforts were aimed to accomplish a more comprehensive management system. Apart from extensions made in the responsibilities of the local authorities in disaster mitigation, three complementary organizations were introduced. Ministry of the Interior initiated regional centers for relief and emergency operations. A General Directorate of Emergency Management was established and attached to the Prime Ministry, and an independent National Earthquake Council was formed by a Prime Ministry mandate.

New Legal Provisions (decrees, laws and mandates)

The Law 4452 (27.08.1999) authorized the government in its actions for the immediate and long-term measures concerning disasters, to issue decrees and regulations as necessary concerning the earthquakes. The Ministerial Board and central bodies of government have issued numerous decrees, mandates, directives, regulations, etc. since 1999 (as listed in Table 3.1). The most important innovations have been those related to mitigation policies. The decrees covering the 'obligatory building insurance' system, the attempt to institute 'building control firms', and 'professional proficiency', the regulation of the rights and liabilities of practice in the building professions have been the most relevant attempts to consolidate mitigation policy. These decisions have moved the concept of disaster management in Turkey from one focused on crisis management to one focused on a broader comprehensive concept of disaster risk management and risk reduction.

Apart from the decrees, most of the steps taken to improve the existing state of affairs are done by means of 'regulations' and 'mandates' of the Ministry of the Interior, MPWS, or the Treasury. The existing decrees of the Board of Ministers are in the process of being reviewed by the Parliament to obtain their consent and become effective as Law of the Republic in due course. It is crucial that such experience and the unprecedented pool of decisions taken by the government during the past years, find their way to build up a new collective system of responding to disasters more effectively. The most valuable outcome will be the institutionalization of mitigation methods, and the formulation of an overall strategy for sustained administrative conduct related to disasters. This transformation implies institutional and legal changes, the adoption of new tasks and responsibilities by the public and private actors, and the restructuring of the relative functions and positions of existing professions.

Local Conduct of Post-Disaster Planning

After the 1999 earthquakes, all plan implementation and building permission powers of local authorities in the disaster region were suspended according to the Disasters Law (7269). All development activity was halted. The Ministry of Public Works and Settlements pre-empted the local authorities, establishing the damage, identifying those entitled to compensations, carrying out extensive geological investigations for new development areas, preparing plans and projects for new housing settlements and tendering their construction. Though this pre-emption of what are normally local prerogatives is possible in the aftermath of a major disaster, the current decentralization of development regulatory functions leaves the municipalities with primary responsibility for earthquake mitigation and risk reduction in the long-term.

3.3 Microzonation as Basis for Land Use Management

General

Microzonation maps at appropriate planning scale, representing the distribution of relative ground shaking, liquefaction landslide and surface faulting potential provide the basis for effective earthquake safety planning at the scale of the municipality. The two principal considerations in earthquake loss reduction are siting and design. The earthquake hazard is spatially distributed in relation to earthquake sources (faults) and local geological and soil conditions. Mapping of variation in earthquake hazards at the municipal scale makes it possible to select relatively safer sites for the allocation of appropriate uses in optimal exploitation of land resources to minimize losses, for appropriate building development and to anticipate particular hazards at a given site. Urban development patterns can be oriented toward relatively safer zones. Knowledge of the variation of earthquake hazards at the microzone level also is valuable to the structural designer and builder to anticipate problems related to amplification of shaking, liquefaction, landslide and fault rupture.

Large-scale macroseismic risk maps (Seismic Risk Map of Turkey) indicate the gross zones of expected earthquake effects based on seismological investigation and historical experience. Such maps provide general guidance for the application of building codes and for the evaluation of regional seismic risk. Seismic microzone maps provide a more detailed evaluation of potential earthquake effects, which can provide valuable guidance in urban planning and development. At the urban level, finer differentiation of seismic effects are more relevant and valuable since greater spatial variability in vulnerability levels are involved due to contrasting concentrations of distinct specializations in uses and buildings. Identification of areas of relative risk due to differentiated seismic hazards can be used to introduce earthquake safety as a factor in key development and siting decisions. Microzone maps provide earthquake hazard information at the appropriate scale for urban development planning and land use management. Detailed site information for specific building design may still require site-specific investigation.

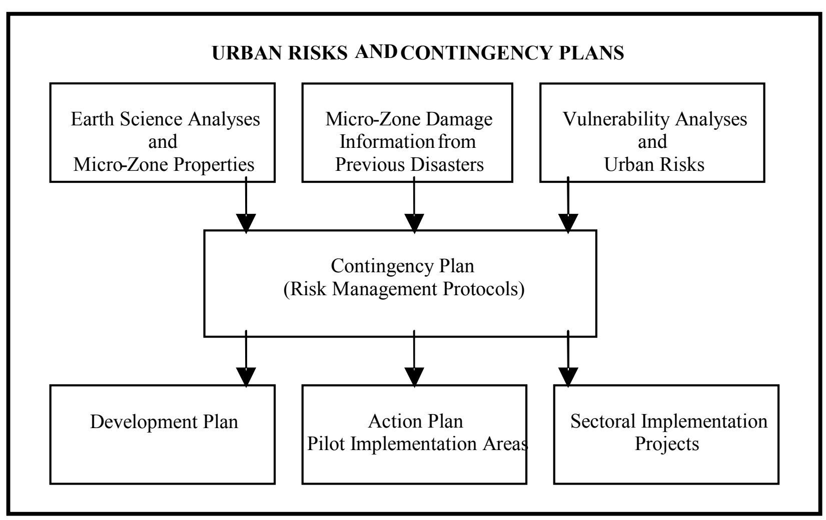


Figure 3.4: Urban Risk and Contingency Plans

Planning Applications of Seismic Microzonation

Microzonation maps can be applied to development of general Urban Development Master Plans as well as used in the management of development. Microzonation of earthquake hazards can be incorporated as a risk factor in the determination of permitted land uses. In the absence of a formal land use management system microzonation can provide guidance in the activities described below.

Comprehensive Planning and Zoning

In the creation of urban development master plans, it is possible to evaluate the relative desirability of development options. Selection of sites for urban expansion and location of key facilities can be directed toward areas of relatively lower earthquake hazard. Areas of amplified ground shaking, liquefaction and landslide can be avoided. Safe siting reduces the likelihood of damage and may reduce the cost of safe construction.

Review of Development Applications

Seismic microzonation maps may be used to review development plans to assess specific known earthquake hazards associated with particular sites. Where appropriate, development may be limited to safer areas or limited to safe scale. In any case the microzonation map can be used to inform the developer, property owners, and the public at large of the particular earthquake hazards, which must be taken into account in design and construction.

Site-Specific Seismic Hazard Evaluations

Seismic microzonation maps do not provide detailed hazard parameters at the level of the specific building site. However, they so provide guidance to the Municipal Planning Department on where site-specific investigations should be required.

Planning, Siting and designing of Public Facilities and Utilities

At the urban scale, seismic microzonation maps provide useful guidance or the siting of public facilities and utilities. Public facilities such as schools, hospitals, police and fire stations should be located on the safest sites available as much as possible. These types of facilities also tend to guide private development. It is, therefore, important that they guide development into relatively safer areas. Utilities are critical to the functioning of a municipality. Care must be taken in the siting of utility systems to avoid recognized areas of elevated earthquake hazard. Critical system components such as electrical substations and water pumping stations should avoid sites prone to liquefaction or landslide. Care should be taken in the design of network systems, which cross elevated hazard zones and special segments of known faults.

Redevelopment and Seismic Retrofit

Seismic microzonation maps for a municipality will also indicate hazard zones for currently developed areas. In this case, the maps can be used to identify areas of critical exposure. For example, the location of a key facility such as a hospital or school in a zone of elevated hazard would suggest that it should be investigated for structural adequacy and possibly considered for strengthening or relocation. Many existing buildings are not adequately constructed to withstand expected earthquake forces. The seismic microzonation maps can help to set priorities for building strengthening and replacement. In the case of redevelopment, seismic microzonation can help to identify areas of highest risk and to identify areas suitable for relocation.

Emergency Management

Seismic microzonation provides a valuable tool for municipal emergency response planning. It provides the basis for the identification of the zones of the municipality most likely to experience serious damage in the event of an earthquake. Though emergency response is the responsibility of the governorate, this information can be used to prepare materials and equipment for emergency response and to develop training scenarios for emergency personnel.

Development plans could be revised so that special land use planning safety standards could be enforced.

Guidance for the Integrated Use of Financial and Other Tools

Seismic microzonation could also provide a basis for the market encouragement for development in safer areas and discouragement for development in more hazardous areas. Explicit information on hazards will generate responsive behavior in the market. To reinforce such effects however, municipalities may choose to integrate their land use guidance with financial tools and property rights. Thus for the imposition of differential property taxation, and insurance, and exercise of locational constraints in property rights and management, the microzonation maps and appropriate land use policies can provide the basic information for attaining safer development.

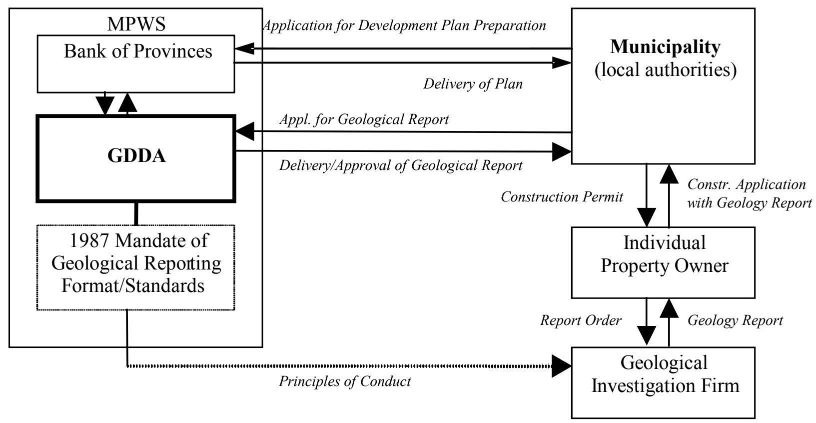
3.4 Managing the Microzonation Process

General

This manual provides guidance on the required procedure for development of seismic microzonation maps at the municipal level. This process has been developed with the cooperation of the General Directorate of Disaster Affairs of the Ministry of Public Works and Settlements. This is an expansion, improvement and standardization of the existing requirement for geological studies in areas subject to earthquake hazards. The process of seismic microzonation and the preparation of municipal seismic microzonation maps must be managed by an appropriate technical unit of the municipality. This may be the Department of Planning or another related unit. The municipality is expected to contract with a technically qualified organization, which will carry out the field investigations, data collection, analysis and map preparation. Seismic microzonation maps will be reviewed and approved by the General Directorate of Disaster Affairs. Final seismic microzonation maps will be incorporated in urban development master plans, provide the basis for municipal expansion plans and be maintained to provide guidance for public and private land development, building and mitigation investment decisions.

The division of responsibility between municipal and central authorities is complex and dynamic. There are strong tendencies to decentralize responsibility for municipal management in the interest of increased democratic control and harmony with local interests and values. However, there remain serious questions of resource availability in many municipalities. Particularly, small municipalities are often unable to support the necessary technical staff to manage a task as complex as seismic microzonation. Previously, technical expertise was concentrated in the agencies of the central government. Currently, more responsibility is being passed from the central government agencies to the municipalities. This shift of responsibilities requires a parallel shift of resources and technical capability.

Geological Investigations According to Legal Provisions



Conduct of Geological Investigations After 1999 Earthquakes

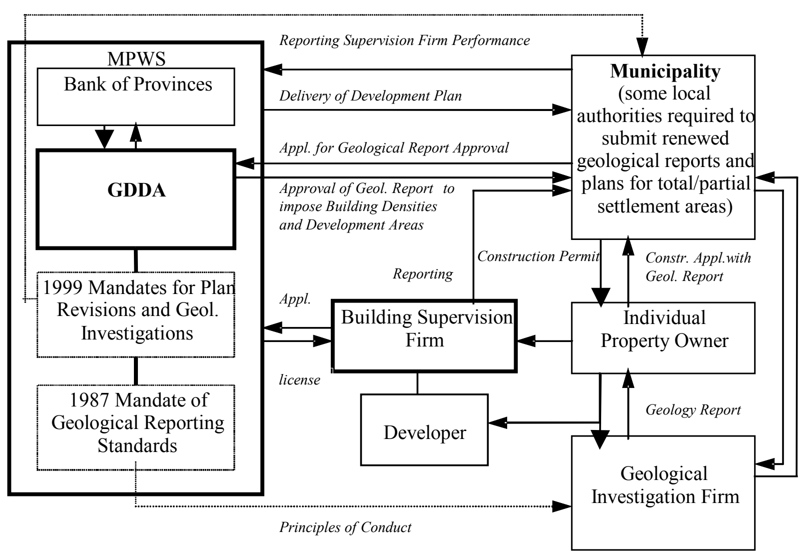


Figure 3.5: Conduct of Geological Investigations

3.4.1 Basic principles, results

Basic principles

The microzonation procedures should be adjusted to the development of the state of technology at regular time intervals, with special consulting support.

The results of the microzonation projects have to be submitted by the municipality to the responsible government agency for approval.

The following sections define the minimum requirements for:

- Planning
- Evaluation of data and
- Implementation in the land use management of the municipality.

Microzonation of a municipality has to be reviewed and appropriately revised:

- After an earthquake affecting the municipality, by taking the damage pattern in the municipality into account.
- Every 15 years, taking into account the accumulated new geological, geophysical and geotechnical data and the new state of technology.

Results

The microzonation projects commissioned by the municipalities have to produce the following results:

- Regional earthquake hazard at a scale of 1:25,000,
- Surface faulting map at a scale of 1:25,000,
- Ground shaking map at a scale of 1:5,000,
- Liquefaction susceptibility map at a scale of 1:5,000,
- Landslide and rock fall susceptibility map at a scale of 1:5,000,
- Assessment of earthquake-related flooding susceptibility

3.4.2 Organizational set-up and responsibilities

Organization

It is recommended that the following organization structure be established:

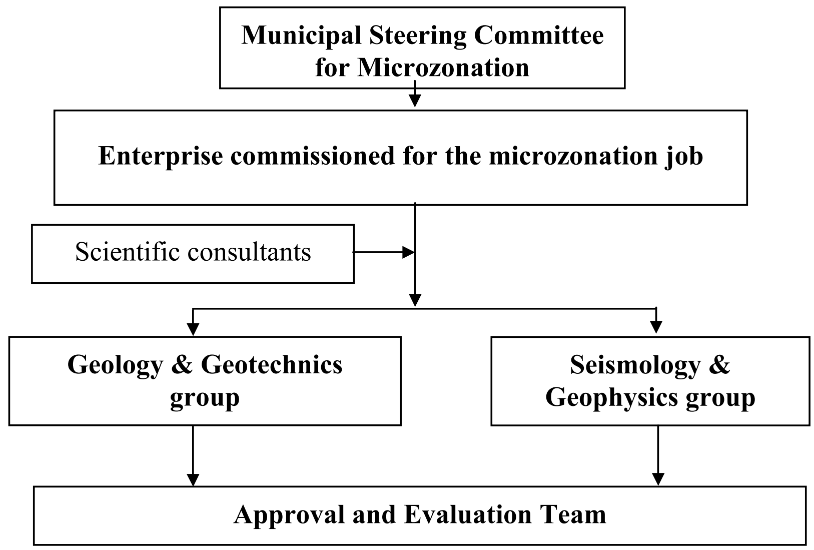


Figure 3.6: Participants in Microzonation Process

Responsibilities of the approving agency

The approval and evaluation team has the following responsibilities:

- Maintaining the microzonation procedure, taking into account the experience in Turkey and the international state-of-the-art
- Interfacing with other governmental agencies for exchange of data and information
- Guiding microzonation studies in selecting suitable consultants and companies (e.g. establishing a list of suitable companies and consultants)
- Reviewing the microzonation projects with the predetermined criteria in Chapter 2.

<u>Recommended members:</u>
Experts in the fields of geology, seismology, geophysics and geotechnical engineering with experience in microzonation.

Responsibilities of Municipal Steering Committee

The Municipal Steering Committee has the following responsibilities:

Planning
- Defining the area in which microzonation has to be performed
- Defining a general work plan indicating work steps to be performed as a basis for a general cost estimate and procurement of services
- Providing appropriate funding
- Selecting the private or public enterprise for microzonation study
- Assuring that all locally available data and information are provided to the selected enterprise

Supervising the ongoing work.

Implementation
The results of the microzonation studies have to be submitted to the responsible agency and, after approval, integrated into the land use plans of the municipality (building and land use zones).

Maintaining the Microzonation
It is recommended that municipalities collect all geotechnical, geophysical and geological data resulting from the ongoing building activities from their territory. These data can be used for the enhancement and updating of the individual microzonation maps.

Recommended members:

- Head: Deputy Mayor or equivalent
- Members: Representatives of the municipal departments responsible for construction and planning

Responsibilities the enterprise commissioned for the microzonation job

The enterprise commissioned for the microzonation job has the following responsibilities:

- Definition of detailed work plan
- Establish geology/geotechnics and seismology/geophysics groups
- Commission scientific consultants to advise on data evaluation and derivation of microzonation maps
- Coordination of microzonation work
- Leading evaluation team
- Regular information flow to the Steering Committee

Professional requirements:

- Should have experience in microzonation projects

Responsibilities of the scientific consultants

The scientific consultants have the following responsibilities:
- Providing technical advice to the enterprise commissioned for the microzonation job to facilitate the technical decision process.

Responsibilities of the geological/geotechnical group and geophysical group

The geology/geotechnics and seismology/geophysics groups have the following responsibilities:

- Data acquisition and evaluation, which is executed using up-to-date equipment and technologies. The personnel involved must have the requisite professional education and training, including continuing professional development in this field.
- Their work must be properly documented and separated into the original raw data, processed data and interpreted results (criteria and format etc., see chapter 2).
- Mapping of raw data, base maps and microzonation maps.

<u>Recommended members of the geology/geotechnics group:</u>

- Head: deputy project manager No.1; Professional qualification: experienced geotechnical engineer with experience in soil dynamics and geology, or engineering geologist with extensive experience in geotechnical engineering and soil dynamics.
- Members: selected representatives of commissioned companies and consultants.

<u>Recommended members of the seismology/geophysics group:</u>

- Head: deputy project manager No. 2; Professional qualification: geophysicist with experience in engineering geology and soil dynamics and knowledge in engineering seismology.
- Members: selected representatives of commissioned companies and consultants.

Responsibilities of the evaluation team

The responsibilities of the evaluation team are:

- Evaluation and completion of data
- Derivation of comprehensive microzonation maps

<u>Recommended members of the evaluation team:</u>

- Head: project manager.
- Members: deputy project managers No. 1 and 2, selected representatives of geotechnical, geological and geophysical groups, scientific consultants.

3.4.3 Microzonation method and responsibilities

Phases of the Microzonation process

It is recommended that the project phases mentioned below should be followed. Technical details for each step are given in Chapter 2.

- Initiation phase
- Detailed planning phase
- Raw data acquisition and establishing of a database/GIS
- Evaluation and completion of data, additional investigations
- Mapping of raw data
- Derivation and mapping of base maps
- Derivation and mapping of microzonation maps

The following phases should be followed when performing a microzonation study:

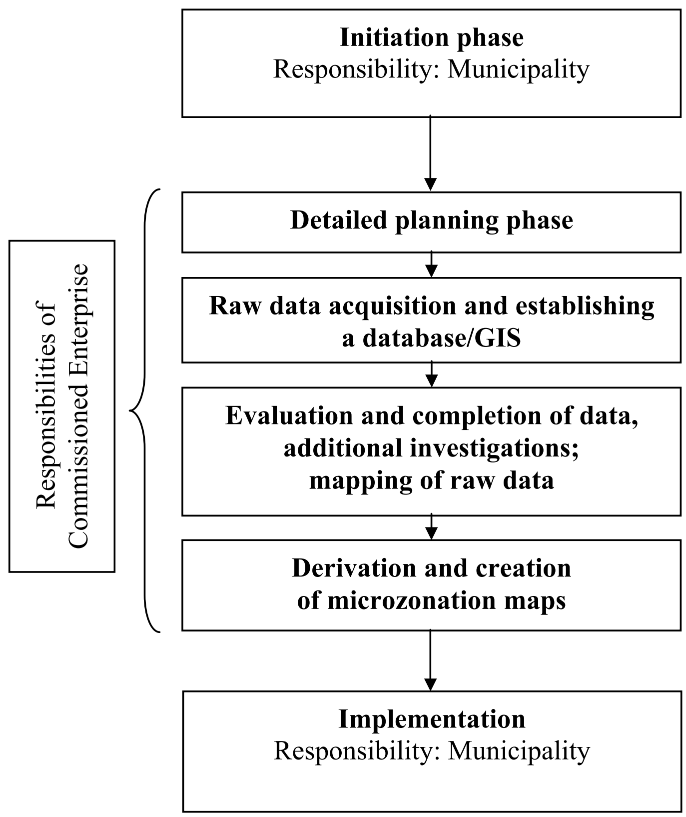


Figure 3.7: Microzonation Management Process

3.4.4 Interpretation of seismic microzonation maps

Microzonation maps

The final products of the seismic microzonation investigation and mapping process is a set of six maps for the territory of the municipality:

1. Surface faulting map
2. Ground shaking map
3. Liquefaction potential map
4. Landslide and rock fall (slope instability) map
5. Earthquake-related flooding susceptibility map
6. Relative earthquake hazard map (composite)

Surface Faulting Map

The map of surface faulting is of value in the establishment of seismic safety zones. It is common in earthquake-prone areas to restrict building in an area with known fault rupture.

Ground Shaking Map

Earthquakes generate shaking in bedrock that is then transmitted through the soil to the ground surface. Some soils dampen the ground motion while others amplify it, causing unusually strong or prolonged shaking that can increase damage to structures. Areas subject to amplified ground shaking can be safely developed if rigorous attention is paid to application of requirements for seismic design and construction. Where possible, it is of course preferable to avoid areas subject to higher relative ground shaking. Adequate consideration of elevated ground shaking can add to building cost. But experience shows that additional earthquake-related costs for new buildings are minimal, in the order of few percent in maximum, whereas the upgrade of existing buildings can be very costly.

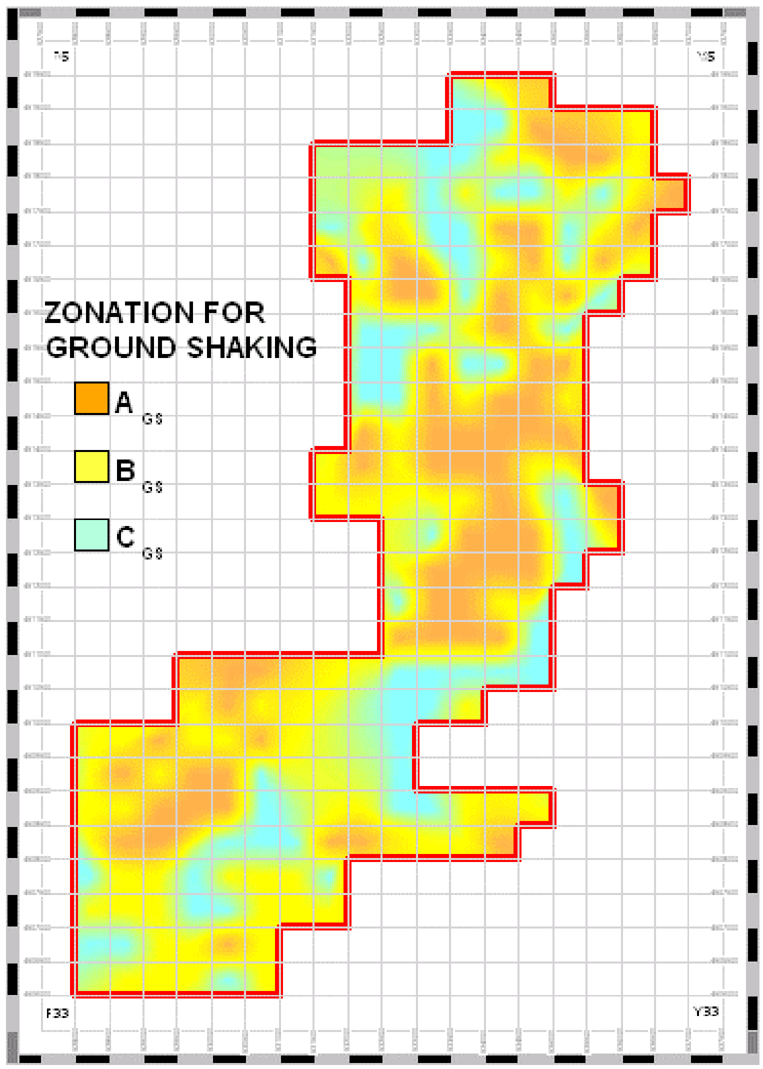


Figure 3.8: Ground Shaking Map for Adapazari

Liquefaction Map

Liquefaction is the phenomenon in which certain soils below the water table lose strength when shaken and become like a liquid. Liquefaction alone does not cause damage, but if the liquefied soil can flow, the ground surface may settle or spread apart, damaging structures, roads, and infrastructure networks. Liquefaction is most likely to occur in sandy soils in area of high ground water table along rivers, creeks, lakes and other bodies of water or in areas of hydraulically placed sand fills. The effects of liquefaction are generally more severe when the liquefiable layers are thick. One of the most damaging effects of liquefaction is lateral spreading. When the underlying soils liquefy, the ground surface may move sideways and settle unevenly, breaking into blocks with fissures between them. Lateral spreading is very damaging to structures and especially to highways, railroads, bridges, and buried infrastructure systems such as those carrying water, sewage, storm water, electricity and communications.

The liquefaction map should be applied to the urban master plan to avoid construction of structures or infrastructure over areas of high liquefaction potential. Where such construction cannot be avoided, appropriate structural provision for anticipated liquefaction must be required.

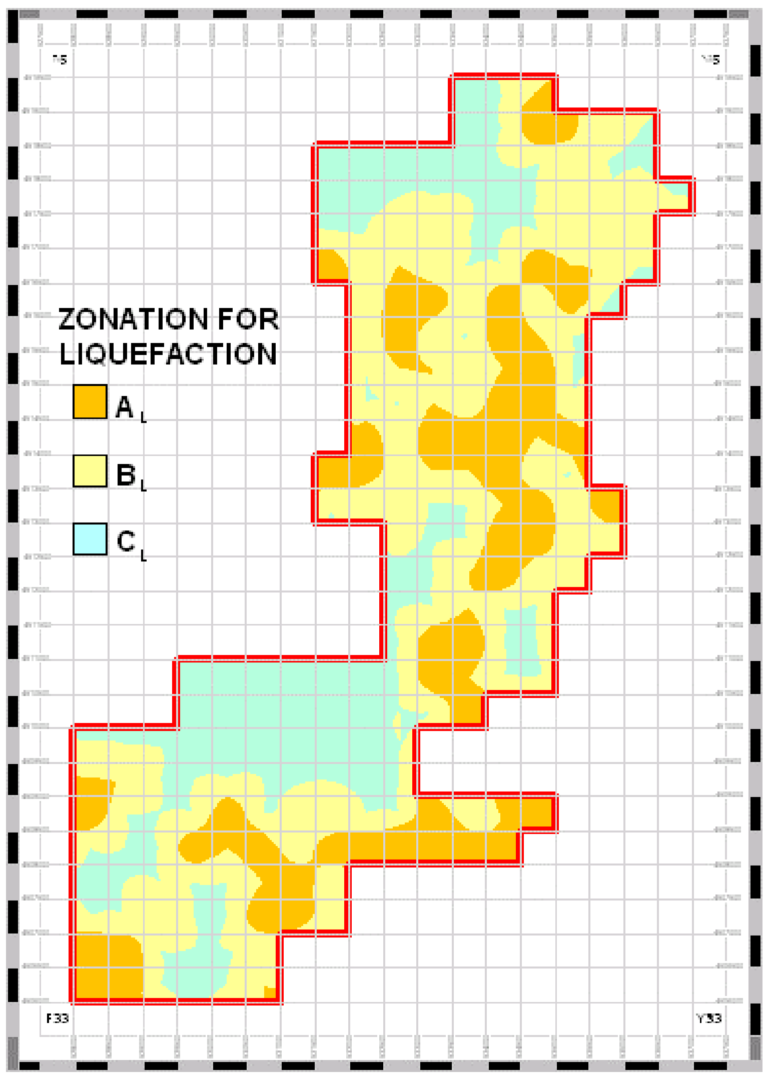


Figure 3.9: Liquefaction Map for Adapazari

Land Slide Map

Landsliding or slope instability in areas with hilly terrain, including both steep and gentle slopes and along riverbanks. Earthquake shaking can trigger landslides on slopes that are otherwise stable, however, the less stable a slope is under non-earthquake conditions the more susceptible it is to failure in an earthquake. Landslides are very damaging to structures built on or below slopes that fail. It is preferable to avoid construction on or below unstable slopes. If construction is necessary in such areas it requires special geotechnical site investigation and specifically qualified design and construction.

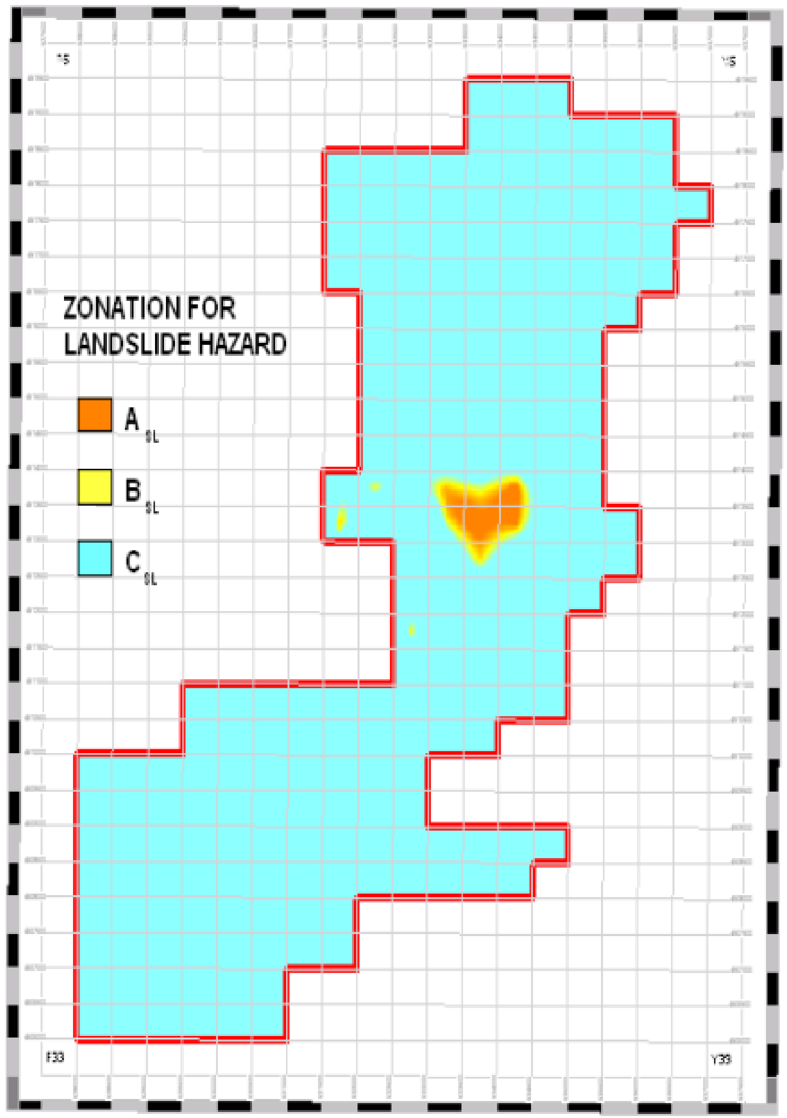


Figure 3.10: Landslide Map for Adapazari

Earthquake-related Flooding Map

Earthquake induced flooding can result from the seismic effects on bodies of water such as seas, bays and lakes and from the earthquake induced failure of dams or reservoirs. Earthquake induced flooding at the seacoast is referred to as tsunami. Anticipated tsunami run-up can be mapped on the basis of expected source zones and the characteristic of sea floor and coastal topography. Flood plains below dams and reservoirs can also be mapped in anticipation of potential structural failure. Such potential earthquake-induced flooding should be taken into account in the location of new development areas, the location of new infrastructure systems and the establishment of priorities for the relocation and renewal of existing settlements.

Use of microzonation maps

The microzonation maps give valuable scientifically based information on the earthquake hazard within a municipality.

They serve as a basis for reducing earthquake risk through:

- Land use management
- Selection of suitable sites for future development of buildings and infrastructure
- Improving the preparation of municipal response following an earthquake disaster

Identification of four classifications of earthquake hazard based on seismic microzonation maps (related to land development classifications for post-earthquake reconstruction)

- Sites suitable for construction
- Sites requiring detailed investigation and specific technical review
- Sites on which all construction is prohibited (immediate fault rupture zone)
- Sites on which new construction is prohibited

Selection of suitable sites for new critical infrastructure elements. Examples:

- Hospitals
- Schools
- Fire and police stations
- Communications centers
- Electrical substations

3.5 Application of the Seismic Microzonation Maps to Urban Master Planning and Development Control for Earthquake Safety

3.5.1 Introduction

While the current legal basis for land use management is limited in Turkish municipalities, important opportunities exist for the reduction of earthquake risk through appropriate land use management by municipal authorities. As provided for in current regulations, municipalities must carry out geological studies to be incorporated in required urban master plans. This manual provides the new standard for those required studies. As described in Chapter 2, the seismic microzonation process incorporates state-of-the-art scientific methods for the collection and interpretation of comprehensive data from seismology, geology and geotechnical engineering. This represents a significant improvement and standardization of methods used for previous geological studies.

Function	Relative Earthquake Hazard	Relative Ground Shaking Amplification	Relative Liquefaction Hazard	Relative Landslide Hazard	Surface Fault Rupture	Earthquake Induced Flooding
Urban Master Plan	M	M	E	E	E	E
Development Plan Review	L	M	E	E	E	E
Site Investigation Requirement	L	E	E	E	E	L
Siting of Public Facilities	M	M	E	E	E	E
Redevelopment, Rehabilitation Planning	M	M	E	E	E	E
Emergency Preparedness	E	E	E	E	M	E

(L = Limited Usage M=Moderate Usage E= Extensive Usage)

Figure 3.11: Use of Seismic Microzonation Maps by Municipalities

Municipal planners will find the maps showing slope instability and liquefaction potential highly useful for comprehensive urban master planning and for review of specific development applications. All five maps are valuable to indicate sites where site-specific seismic investigations should be required and in setting priorities for redevelopment projects and seismic rehabilitation programs for existing buildings. The liquefaction and landslide and rock fall maps are useful in the siting of public facilities and infrastructure systems. Emergency response planners at all levels of government will benefit from all five maps in the creation of public education programs, earthquake hazard mitigation programs and response plans.

3.5.2 Application of Seismic Microzonation to Urban Master Planning

Municipalities with population greater than 10,000 are required to establish and maintain urban master plans. These urban master plans are submitted to the Ministry of Public Works and Settlements for review. The General Directorate of Disaster Affairs of the Ministry reviews the disaster risk components. Expansion of "land suitable for urban development" is proposed in the urban master plan. The selection of such suitable land must take into account the relative earthquake hazard indicated on the seismic microzonation maps.

The relative earthquake hazard map, which represents a composite of the earthquake hazards presented on the five component maps, is most valuable for the determination and comparison of overall seismic risk, which is relevant in the selection of rural lands for the expansion of municipal boundaries. Where possible, the best approach to seismic risk is to avoid it.

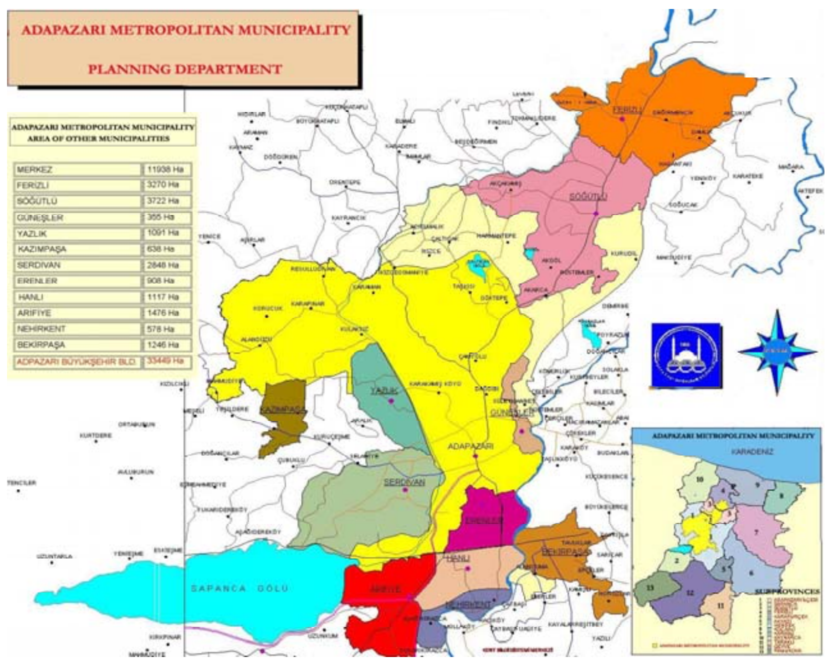


Figure 3.12: Master Plan for Expansion of Adapazari

3.5.3 Relative Earthquake Hazard Map

The hazards depicted on the five maps of individual hazards are additive. A given location can experience a combination of these effects. Recognizing the importance of an integrated view of hazards for the planning process, a composite map has been developed to represent the distribution of the principal hazards of ground shaking, liquefaction and landslide. This map shows at a glance where the effects of an earthquake are likely to be most severe. This combined map is created for people with little or no technical knowledge of earthquakes and their effects. It shows three zones arranged in order of severity of effects. From Zone A (red), the most hazardous, to Zone C (blue), the least hazardous.

Procedure and Criteria for the Preparation of the Combined Map

The proposed procedure to prepare a combined hazard map includes the following steps:

1. The different zones resulting from the singular microzonation maps are labeled as following:
- Surface faulting map: Zones A_{SF} and C_{SF}
- Ground shaking map: Zones A_{GS}, B_{GS}, C_{GS}
- Liquefaction susceptibility map: Zones A_L, B_L and C_L
- Land slide and rock fall susceptibility map: Zones A_{SL}, B_{SL} and C_{SL}
- Earthquake related flooding susceptibility map: Zones A_F and C_F

2. Assign the following numerical values to the defined zones:

Zone	**Value Z_i**
A_{SF}	2
C_{SF}	0
A_{GS}	2
B_{GS}	1
C_{GS}	0
A_L	2
B_L	1
C_L	0
A_{SL}	2
B_{SL}	1
C_{SL}	0
A_F	2
C_F	0

Depending on the specific use of the combined hazard map, weights w_i can be assigned to specific hazards.

3. Calculate for each square:

$$V = \sum_i (Z_i \cdot w_i)$$

for i = SF, GS, L, SL, F
with Z_i: Corresponding zone value of given point in map i
w: weight of map I

4. Establish the criteria for the 3 zones in the combined hazard map.

   The proposed criteria is:

$V \leq 1/6\ V_{max}$	Low hazard
$1/6\ V_{max} < V \leq ½\ V_{max}$	Medium hazard
$V > ½\ V_{max}$	High hazard

For the Adapazari combined hazard map, the corresponding values are the following ($w_i = 1$):

Zone	V
A: Low combined earthquake hazard	$0 \leq V \leq 1$
B: Medium combined earthquake hazard	$2 \leq V \leq 3$
C: High combined earthquake hazard	$4 \leq V \leq 6$

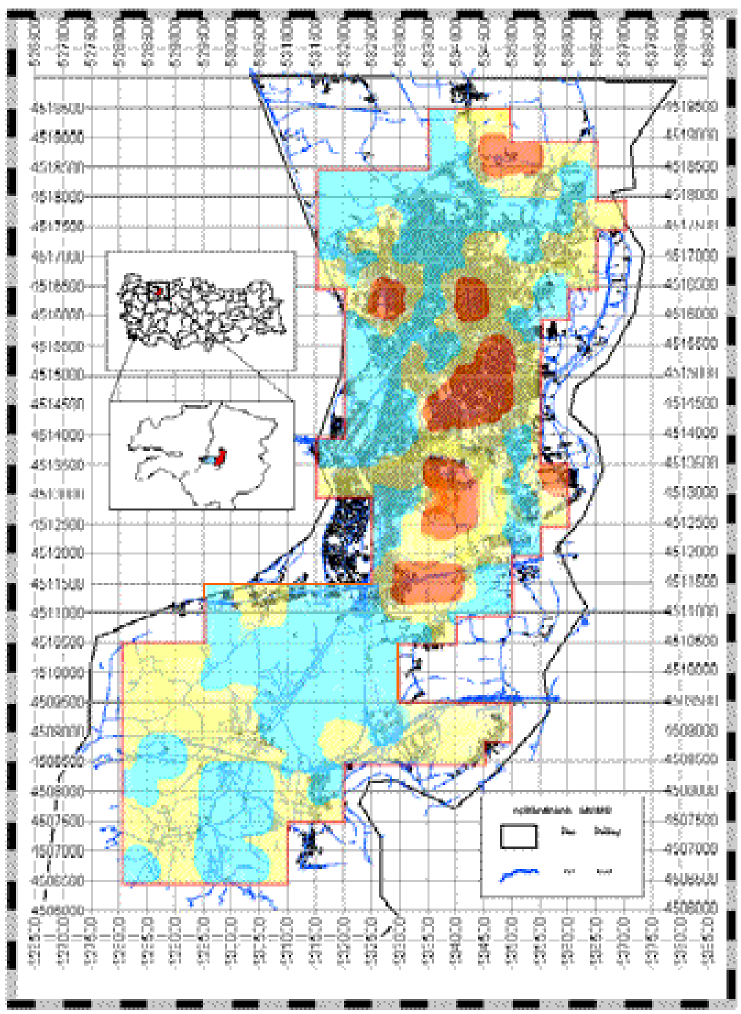


Figure 3.13: Combined Hazard Map for Adapazari

Use of GIS System

A geographic information system (GIS) is a valuable aid in this analytic process. It allows municipal governments to efficiently and systematically combine spatial data from a variety of sources. This ability to layer information allows analysts to see at a glance the net effect of all the factors influencing land use decisions in a given area. The methodology of this manual provides a GIS capability for the integration of earthquake hazard considerations into general land use planning. The General Directorate Of Disaster Affairs has created a Geographic Information Systems and Remote Sensing Unit to provide assistance and oversight for the development of municipal GIS capability for natural hazard management.

Urban master plans are required to include geological studies. However, in the past, standards for these studies were incomplete and there is significant inconsistency in the format and the quality of these studies. Urban master plans are subject to periodic review. As municipal master plans come due for periodic review in the future, microzonation maps will be required according to the procedure of this manual. Microzonation maps will be the basis for the analysis of physical characteristics affecting land use. While the composite map of relative earthquake hazard is of value in assessing the broad lines of projected urban development and municipal expansion, the component maps are most useful in indicating specific control measures. In general, ground shaking is addressed in the Building Code. Ground shaking hazards are best addressed by the strict enforcement of existing building standards to both initial plan review and rigorous construction site inspection. Restrictions on land use are most important to deal with landslide, liquefaction, and other ground failure hazards, which can be triggered by earthquake ground shaking. Specific spatially defined hazard including surface fault rupture and earthquake induced flooding also motivate land use management restrictions.

At the level of the urban master plan the suggested four zone system developed by the General Directorate for Disaster Affairs for post-earthquake site evaluation can be suggested for guidance to public and private development:

- Sites suitable for construction
- Sites requiring detailed investigation and specific technical review
- Sites on which all construction is prohibited (immediate fault rupture zone)
- Sites on which new construction is prohibited

Even in the absence of strict legal authority for enforcement such advisory information is of significant value for both public planners and private investors.

Summary Guidelines:

- **Use the microzonation maps, along with other information, in determining desired land uses and urban growth boundaries.**
- **During periodic review of urban master plans, review and revise, if needed the uses for lands shown as hazardous on the microzonation maps.**
- **Incorporate the seismic microzonation maps into local GIS, if available.**

3.5.4 Application of Seismic Microzonation to Review of Development Applications

Seismic microzonation maps may be used to review development plans to assess specific known earthquake hazards associated with particular sites. Where appropriate, development may be limited to safer areas or limited to safe scale. In any case the microzonation map can be used to inform the developer, the property owners and the public at large of the particular earthquake hazards, which must be taken into account in design and construction.

Summary Guidelines:

- **Use the seismic microzonation maps to determine when seismic hazard evaluations are needed before land is subdivided or services are provided**
- **Before new building plots are approved, use seismic microzonation maps to assess the vulnerability of the lots, access and infrastructure in the event of an earthquake**

3.5.5 Application of Seismic Microzonation: Site-Specific Seismic Hazard Evaluations

Seismic microzonation maps do not provide detailed hazard parameters at the level of the specific building site. However, they provide guidance to the municipal planning department on where site-specific investigations should be required.

Summary Guidelines:

- **Adopt policies to acquire additional seismic hazard information before development of areas shown to be potentially hazardous on seismic microzonation maps.**
- **Establish procedures to require site-specific seismic hazard evaluations.**
- **Seek qualified engineering geologists or geotechnical engineers to review site-specific geotechnical reports submitted by applicants for development permits.**

3.5.6 Application of Seismic Microzonation to Planning, Siting and Designing of Public Facilities and Utilities

At the urban scale, seismic microzonation maps provide useful guidance or the siting of public facilities and utilities. Public facilities such as schools, hospitals, police and fire stations should be located on the safest sites available as much as possible. These types of facilities also tend to guide private development. It is, therefore, important that they guide development into relatively safer areas. Utilities are critical to the functioning of a municipality. Care must be taken in the siting of utility systems to avoid recognized areas of elevated earthquake hazard. Critical system components such as electrical substations and water pumping stations should avoid sites prone to liquefaction or landslide. Care should be taken in the design of network systems, which cross elevated hazard zones and special segments of known faults.

Summary Guidelines:

- **Using seismic microzonation maps, identify potential hazards to be addressed in the selection of sites and design of public facilities and infrastructure systems.**
- **Use the seismic microzonation maps to help guide investment in strengthening and mitigation measures for public facilities and infrastructure.**

3.5.7 Application of Seismic Microzonation to Redevelopment and Seismic Retrofit

Seismic microzonation maps for a municipality will also indicate hazard zones for currently developed areas. In this case, the maps can be used to identify areas of critical exposure. For example, the location of a key facility such as a hospital or school in a zone of elevated hazard would suggest that it should be investigated for structural adequacy and possibly considered for strengthening or relocation. Many existing buildings are not adequately constructed to withstand expected earthquake forces. The seismic microzonation maps can help to set priorities for building strengthening and replacement. In the case of redevelopment, seismic microzonation can help to identify areas of highest risk and to identify areas suitable for relocation.

Summary Guidelines:
- **Use seismic microzonation maps in establishing priorities for redevelopment to relocate existing settlements to less hazardous sites and to create safer land uses and buildings in the course of redevelopment.**
- **Use seismic microzonation maps with structural and other information to set priorities for seismic retrofit for existing hazardous buildings and facilities.**

3.5.8 Application of Seismic Microzonation to Emergency Management

Seismic microzonation provides a valuable tool for municipal emergency response planning. It provides the basis for the identification of the zones of the municipality most likely to experience serious damage in the event of an earthquake. Though emergency response is the responsibility of the governorate, this information can be used to prepare materials and equipment for emergency response and to develop training scenarios for emergency personnel.

Development plans could be revised so that special land use planning safety standards could be enforced.

Summary Guidelines:
- **Use the seismic microzonation maps to inform the public on the earthquake vulnerability of the municipality and the region.**
- **Use the seismic microzonation maps to create realistic scenarios for emergency planning and training exercises for municipal level organizations.**
- **Use the seismic microzonation maps to evaluate the vulnerability to earthquake damage in addressing hazardous material storage, transport and use.**

3.6 Land Use Management Administration for Earthquake Safety

3.6.1 General remarks

The critical element in the system of disaster risk management is implementation. While scientific understanding of the earthquake phenomenon and engineering understanding of the processes of earthquake-induced structural failure have grown markedly over the past century, earthquake losses continue to grow at a rapid rate. There is a very unfortunate gap between what we know about earthquake safety and what we do about earthquake safety. Because earthquakes do not occur on a regular basis in any specific place, people do not necessarily gain experience of losses to guide their land use and building decisions. The return period for earthquakes affecting the same site may be considerably longer than a generation. For this reason the consequences of poor construction or inappropriate land use do not always fall on those responsible for the poor judgement. It is therefore of critical importance that the values of earthquake safety be institutionalized in a mechanism more reliable than human memory or intention. Regulatory measures for earthquake safety are the fundamental tool of society to deal with such a long-term, intergenerational issue.

Municipalities are granted police powers to protect the health, safety and welfare of their citizens. These powers must be exercised rigorously in the interest of long-term public safety and welfare. Developers and builders must be held accountable for the safety of future occupants of their buildings. The mechanisms available to enforce this accountability are public regulation of land use and building standards. The administration of municipal regulations related to public safety is a high moral calling.

Typically, it is the planning department of a municipality that is charged with the development and management of the urban master plan. The urban master plan reflects the collective values and aspirations of the citizens of the municipality. It represents a balance of public and private interests, a balance of development and preservation of nature and culture, and it represents a statement of acceptable risk or public safety. The designation of areas of relative earthquake hazard is a means to protect life and property. The provision of advice on and the enforcement of earthquake safety regulations is a critical function of municipal planning and building officials.

Many municipalities lack adequately trained technical staff to carry out effective land use management. Many planning departments lack adequate authority and local political support to carry out enforcement of land use management regulations.

3.6.2 Requirements for Implementation of Land Use Management for Earthquake Safety

Professional Technical Staff

While the demand on technical staff vary depending on the size of the municipality, a very rough rule of thumb is that there should be at least one professional planning staff person for every 5,000 inhabitants. The planning department staff must include a balance of the appropriate certified professionals including:

- Urban Planners
- Architects

- Civil Engineers
    - Structural
    - Geotechnical
    - Environmental
- Cartographers
- Data Management Specialists
- Geographic Information System Specialists
- Field Investigators

Facilities for Plan Development, Review and Enforcement

A critical requirement for land use management is spatial data information management. To take full advantage of currently available data sources, it is imperative that every municipality establish a GIS capability as soon as feasible. The availability of computerized data management makes possible the efficient maintenance and use of map databases.

3.6.3 Primary Functions of the Planning Department to Ensure Earthquake Safety

Master Plan Development, Review and Maintenance

A primary function of the municipal planning department is the oversight and maintenance of the urban master plan. In many cases this may take the form of managing the work of external consultants. The planning department will also have a primary responsibility for the selection and management of the consultants who carry out the seismic microzonation studies and produce the seismic microzonation maps described in this manual. It is the responsibility of the planning department to ensure that the earthquake hazards represented in the microzonation maps are introduced appropriately in the urban master plan.

Plan Review

When development proposals are submitted to the planning department for review, it is the responsibility of the department to inform the developer of all seismic hazards associated with the proposed development and to enforce all applicable limitations on development. This is the first and most easily accomplished action to ensure earthquake safety. Revision of plans is far less expensive than removal of completed structures.

Site Inspection

It is critical to carry out site inspections during and following construction to ensure that the conditions of the approved plan are executed properly. Site inspection is a time-consuming and technically challenging activity but it is essential to the process of earthquake safety regulation.

Enforcement

Enforcement is the most difficult and most important step in the regulatory process. Enforcement is necessary for the process to be taken seriously. It requires strong local political support and it requires the exercise of police powers in the physical removal of non-conforming structures. Enforcement is possible when the general public understands the importance of earthquake safety regulation to their future well-being.

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