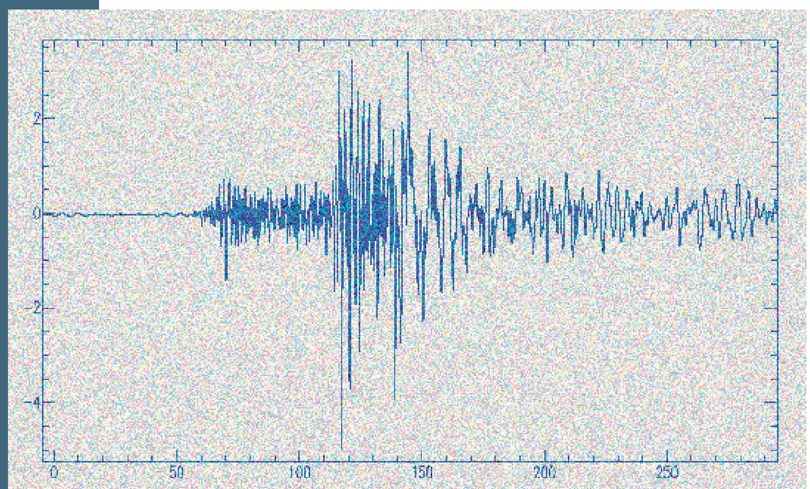
WORLD HEALTH ORGANIZATION
EUROPE




# Health facility seismic vulnerability evaluation

– a handbook –

# Health facility seismic vulnerability evaluation

## A handbook

Disaster Preparedness and Response Programme (DPR)
Division of Country Support, Country Policies, Systems and Services (DCS/CPS)
World Health Organization, Regional Office for Europe (WHO/EURO)

**Keywords**

Address requests about publications of the WHO Regional Office to:
Publications
WHO Regional Office for Europe
Scherfigsvej 8
DK-2100 Copenhagen Ø, Denmark
Alternatively, complete an online request form for documentation, health information, or for permission to quote or translate, on the Regional Office web site (http://www.euro.who.int/pubrequest).

# CONTENTS

# FOREWORD: "Hospitals safe from disasters" a priority for preparedness programmes

*The World Health Organization Regional Office for Europe is, within the framework of the strategy of "Matching the services to country needs" and in line with the World Health Organization global strategic priorities of "Health Action in Crises", committed to assist its 52 member states in strengthening the capacity of their health systems to respond to future crisis situations.*

*The health sector in general and hospitals and health facilities in particular play an essential role in the response to all kinds of natural or man-made disasters, as the protection of human beings and their health is of primary importance in all emergencies. Strengthening health systems to enable them to provide reliable services in crisis situations, when systems typically tend to be overwhelmed, needs to be promoted as a key area of concern in all European countries. Increasingly, as societies confront new challenges and threats, preparedness efforts have to be adapted accordingly. When chemical, biological, radiological or nuclear threats – or terrorist attacks – are added to the already extensive list of potential technological and natural hazards, essential health services must become better prepared to respond and to function adequately in crisis situations.*

*Lessons learnt from previous crises clearly indicate that sound preventive efforts largely pay off in subsequent emergencies. Preparedness programmes are more effective when they are designed and implemented as a continuous process, based on a sound analysis of hazards and vulnerabilities. Ministries of health, as the government institutions responsible for securing and coordinating the public health response in crises, require political support, including appropriate financial and human resources, to ensure that the health system is prepared for and able to cope with disasters, with reliable hospitals and health facilities being of utmost importance to provide essential services to victims.*

*The WHO Regional Office for Europe, specifically the disaster preparedness and response programme in synergy with other relevant technical units, is committed to cooperating closely with WHO Member States and other stakeholders to achieve tangible results at the country level and to contribute globally to the WHO global expected results. Reliable health facilities – as functioning safe havens for disaster victims in the aftermath of a crisis – have been identified as a potential indicator for the effectiveness of national preparedness programmes. The international Kobe conference in early 2005 and the resulting Hyogo framework for action have highlighted the importance of "hospitals (being constructed in a way that makes them) safe from disasters".*

*The WHO preparedness and response programme offers technical support to countries to effectively promote evidence-supported interventions to prepare for crisis situations, so that avoidable suffering and death are minimized, health systems are protected and repaired, and national authorities and communities enabled to prepare, respond, recover and mitigate the effects of natural and man-made disasters within and across the Region.*

*This handbook has been developed with the assistance of the Institute of Earthquake Engineering and Engineering Seismology to provide practical guidance to hospital managers in assessing the vulnerabilities of health facilities, identifying structural and functional gaps and weaknesses, and collaborating with technical experts to ensure that hospitals and health facilities are constructed in a way that ensures that health services remain functional in the aftermath of disasters, when they are needed most.*

Dr Gerald Rockenschaub
Regional Adviser, Disaster Preparedness and Response
WHO Regional Office for Europe

# PREFACE

*A severe earthquake is one of nature's most terrifying and devastating events, resulting in widespread destruction. Apart from causing, in most cases, huge economic and social disruption, such events also have a sudden and massive impact on the health status and health conditions of the population affected. Experience from past earthquakes throughout the world clearly shows that the health facilities in the affected area are the key to launching an immediate response. There is a widely held expectation that hospitals and other health facilities are prepared to deal with any crisis. In general this may be a valid perception, but past events have demonstrated that health facilities may be particularly vulnerable to earthquakes and therefore rendered unable to respond. The seismic vulnerability of hospitals, if compared to other buildings and installations of equal size and construction, is more complex since it is generated by their structural, functional, technological and administrative/organizational performance.*

*Given the importance of an efficient response to emergencies and the need for a functional health care infrastructure in the aftermath of a disaster, hospital administrators must assess a facility's vulnerability to earthquakes and obtain estimates of existing risk levels in order to ensure a proper response to emergency needs. A reliable and comprehensive hospital assessment can be carried out only by taking into account all three main vulnerability categories – structural, nonstructural and administrative/organizational – in that order.*

*In the light of the principal issues regarding vulnerability reduction in health facilities emanating from the World Conference on Disaster Reduction held in Kobe, Japan in January 2005, the WHO Regional Office for Europe asked the Section for Risk, Disaster Management and Strategic Planning at the Institute of Earthquake Engineering and Engineering Seismology in Skopje to develop a seismic vulnerability evaluation method for health facilities. The method that has been developed will enable hospital administrators to perform a preliminary (qualitative/quantitative) vulnerability assessment, identify possible weak elements in the facility and the main vulnerable areas, and decide on priorities for any necessary further "in-depth" investigations. It takes account of characteristic European features such as the predominant types of building used for health facilities, and uses existing methods for vulnerability assessment and the European Macroseismic Scale for determining the possible seismic demand. Nevertheless, the method is also suitable for the other WHO European Member States in, for example, the Caucasus and central Asia.*

*The Institute of Earthquake Engineering and Engineering Seismology is indebted to the Regional Office for recognizing the need to carry out such an activity as well as for financial support. The authors believe that the proposed method will be widely promoted in the European Region of WHO. Comments and suggestions from the scientific community and from professionals in the field that will result from its implementation will contribute to its improvement, calibration and adjustment to the variety of seismic exposure conditions existing throughout Europe.*

15 July 2005

Dr Goran S. Trendafiloski
Principal Project Investigator

# LIST OF FIGURES AND TABLES

# 1. INTRODUCTION

The hospital is a highly complex facility that, while providing health care, also functions as a hotel (inpatients), an office building (medical staff and administration), a laboratory and a warehouse. It has a high level of occupancy (patients, medical and support staff, visitors) and a lot of expensive medical equipment.

The very nature and purpose of a hospital demands that it remain fully operational in the aftermath of a severe earthquake. Although hospitals are essential for dealing with disasters, their complexity, occupancy level and specific equipment and installations also make them very vulnerable in various aspects: structural (load bearing system), non-structural (architectural elements, installation and equipment) and administrative (organization of space, functions, staff, procedures, etc.).

In areas prone to seismic activity, both existing and planned health facilities must comply with aseismic design codes. These are intended to ensure the safety of the buildings' occupants and to allow facilities to continue functioning during and after the earthquake.

It is well-recognized fact that, owing to the unpredictable character of earthquakes, provision of complete protection against all earthquakes that might (or might not) occur during the economic lifetime of the structure is not economically feasible.

Building codes primarily regulate the design and construction of the structural elements that provide support to the building. Good structural design is the key to a building's survival in an earthquake: damage may occur, but collapse is unlikely. Nevertheless, even if there is little or no structural damage, the facility may be unable to function effectively if nonstructural damage causes critical equipment to be dislodged or overturned, essential or dangerous chemicals to be thrown down from shelves, or lifeline services to be interrupted.

Of all the elements that interact in the day-to-day operation of a hospital, the administrative and organizational aspects are among the most important. These can ensure that disaster prevention and mitigation measures are adopted before a disaster strikes, so that the hospital can continue to function after an earthquake or other catastrophic event.

Risk reduction in hospital design is a responsibility shared by architects, engineers, physicians and administrators. The link between architecture and resistant structural systems must be clear to all involved in the design process in disaster-prone areas.

An effective risk mitigation programme should consider the importance of health facilities in immediate post-disaster conditions, as well as their high seismic vulnerability. Owing to the high cost of health facilities, the impact on public finances and the production capacity of a country due to the high costs of repair and reconstruction should also be taken into consideration.

Given the importance of an efficient response to emergencies and the need for a functional health care infrastructure in the aftermath of a disaster, hospital administrators must consider all aspects of a facility's vulnerability. A reliable and comprehensive hospital assessment can be carried out only by taking into account all three main categories of vulnerability (structural, nonstructural and administrative/organizational, in that order).

It is the duty of authorities to assess a hospital's vulnerability to earthquake damage and to obtain estimates of existing risk levels in order to ensure a proper response to emergency needs. Most hospital authorities have established disaster mitigation and response plans. It is necessary to plan in advance, with the support of public service providers such as the fire service, civil defence officials and transit authorities, in order to draw up cooperation and coordination agreements. All these inter-institutional mechanisms must be taken into account in a hospital's disaster mitigation and prevention plan, on the basis of the vulnerability of its structure, its equipment and its administration and organization.

Various methods for assessing the vulnerability of a health facility exist and they differ in cost, complexity and precision. Most of them treat each vulnerability category separately, and their implementation usually demands a sound engineering background, software and comprehensive data set. Owing to their use of inbuilt vulnerability models, some methods are spatially oriented (i.e. constructed for specific regions) and cannot easily be applied to other regions except where the building typology is similar.

This project, carried out with the collaboration and financial support of the Regional Office for Europe of the World Health Organization (WHO), aims to develop simple integrated procedures that will enable hospital administrators to perform a preliminary (qualitative/quantitative) hospital vulnerability assessment, to identify possible weak elements in the facility and the main aspects of vulnerability, and to set priorities for further in-depth investigations and possible mitigation measures. Any procedure should take account of features characteristic of Europe (such as the typical building types used for health facilities), employ existing methods for assessing vulnerability, and use the latest version of the European Macroseismic Scale (EMS-98) for determining possible seismic demand.

The three main vulnerability categories – structural, nonstructural and administrative/organizational – are discussed in detail in Chapter 2, including the main vulnerability factors for health facilities and a review of the methods used in vulnerability assessment. The health facility integrated vulnerability evaluation (HVE) method is presented in Chapter 3. Details of the utilization of data collection and evaluation forms are also discussed here. Chapter 4 presents the main seismic risk mitigation strategies for reducing structural, nonstructural and administrative/organizational vulnerability. A summary of the overall report is given in Chapter 5.

Annex 1 contains the health facility vulnerability evaluation forms. These comprise (*a*) Form HVE 001 for the general evaluation of the vulnerability of a health facility; (*b*) Forms HSVE 001 and HSVE 002 for evaluation of structural vulnerability; (*c*) Forms HNVE-001/1, HNVE-001/2 and HNVE-001/3 for evaluation of nonstructural vulnerability; and (*d*) Forms HOVE-001/1 and HOVE-001/2 for evaluation of administrative/organizational vulnerability. Annex 2 provides a detailed description of the dominant types of health facility buildings in Europe. Grades of seismic damage to masonry and reinforced concrete buildings according to EMS-98 are presented in Annex 3. Annex 4 includes information on aseismic design codes and seismic hazard levels in the Member States of the WHO European Region. Annex 5 presents examples of seismic damage (nonstructural and structural) to health care facilities.

# 2. SEISMIC VULNERABILITY OF HEALTH FACILITIES

## 2.1. Health facility vulnerability/damageability factors

Health facilities are essential for dealing with the consequences of earthquakes, but they are also highly vulnerable. Other buildings and installations of similar size and construction may exist, but they are not as complex from the functional, technological and administrative points of view. The following factors make health facilities especially vulnerable *(1)*.

*Complexity*. In providing health care, a hospital also functions in some respects as a hotel, an office building, a laboratory and a warehouse. The hotel aspect alone is complex, involving the preparation and serving of food and beverages as well as the provision of lodging. Health facilities generally include many small rooms and long corridors. Patients and visitors will be very confused in the wake of a disaster, when electrical power may have failed and fallen furniture or rubble may block corridors and room exits. Lifts will be out of service and stairways may be difficult to use.

*Occupancy*. Health facilities have a high level of occupancy, with patients, medical and support staff and visitors present 24 hours a day. Many patients require assistance and continuous specialized care. They may be surrounded by medical equipment, use potentially dangerous gases, or be connected to life support equipment that requires an uninterrupted power supply.

*Critical supplies*. Most of the supplies required by health facilities (medicines, splints, bandages, etc.) are essential to patients' survival and crucial to the treatment of disaster victims.

*Basic facilities (infrastructure)*. No facility depends on public services or lifelines more than a health facility, which cannot function without power, water, clinical gases, oxygen, fuel, garbage collection and communications.

*Heavy objects*. Medical equipment and other appliances are often located above or near patients' beds or on high shelves. During an earthquake, such equipment may fall, causing serious injury or obstructing evacuation routes. Other pieces of specialized equipment, such as X-ray machines, backup generators and autoclaves, are extremely heavy and may be tossed about or overturned during an earthquake.

*Hazardous materials*. Many products found in hospitals are dangerous if they spill or leak. The collapse of shelves holding medicines or chemicals can release poisonous liquids or gases. Spilled chemicals, damaged gas cylinders and ruptured oxygen lines can cause fires. The absence of normal security measures can also lead to the abuse of drugs normally kept under lock and key.

*External dependence* (security services and community aid).

Given the importance of an efficient response to emergencies and the need for a functional health care infrastructure in the aftermath of a disaster, hospital administrators must consider all aspects of facility vulnerability. A reliable and comprehensive hospital assessment can be carried out only by taking into account all three main categories of vulnerability in the following order: (*a*) structural; (*b*) nonstructural; and (*c*) administrative/organizational.

## 2.2. Structural vulnerability

### 2.2.1. Background

This category of vulnerability is related to the susceptibility to various types of damage of the structural elements that are required to physically support the building. These include foundations, columns, bearing walls, beams, staircases and floors. For a new building, these factors are considered during design and construction; for an existing structure they are considered during repair, reconstruction or maintenance.

The following contribute to the level of structural vulnerability:

- the level of aseismic protection
- architectural and structural configuration problems
- the quality of materials, workmanship and maintenance.

In areas liable to seismic activity, both existing and planned health facilities must comply with aseismic design codes. These codes are intended to ensure the safety of the building's occupants and to allow the facility to continue functioning during and after a seismic event. The codes themselves cannot guarantee safety from excessive damage, however: they establish minimum requirements, which are continually updated in accordance with technological advances and lessons learned through research and study of the effects of past earthquakes.

The latest advances in aseismic design, such as the concept of performance-based engineering *(2)*, anticipate the acceptability of various levels of damage based on the consequences of this damage to the user community and the frequency with which the damage occurs. If a structure is provided with high earthquake resistance, this reduces costs over its service life related to loss of life, interruption of business, and repair/reconstruction following earthquakes. In an optimal situation, the costs related to providing initial earthquake resistance for a structure would be balanced against the costs related to damage sustained in future earthquakes.

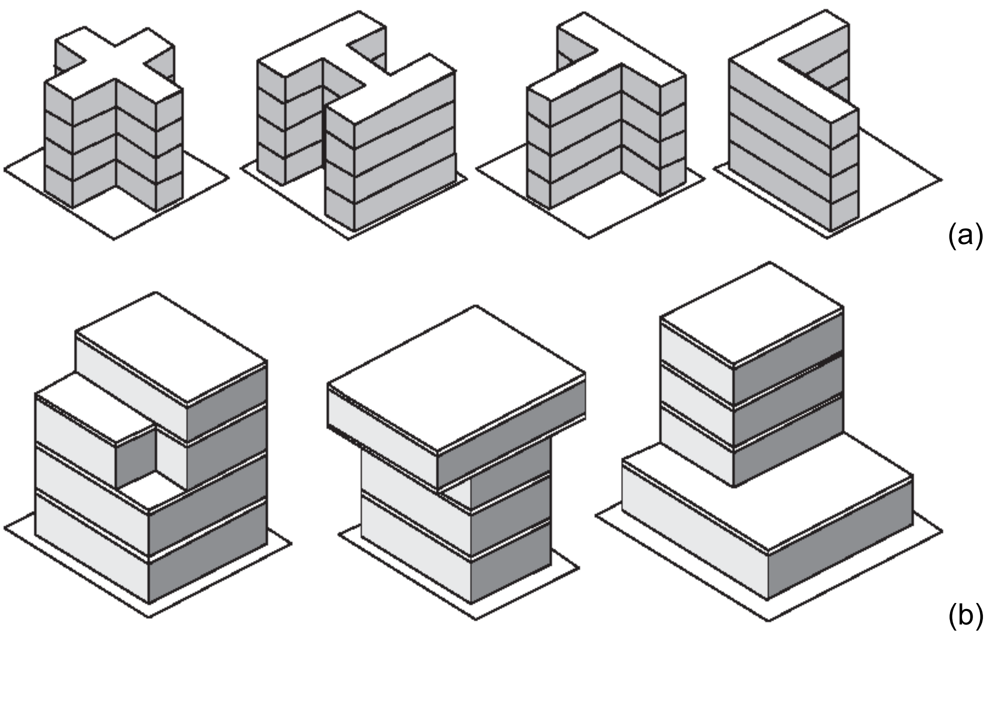
## 2.2.2. Architectural and structural configuration problems

By their nature, health facilities tend to be large and complex, which often causes their configuration to be quite complex as well. Configuration does not refer here simply to the spatial arrangement of the buildings and their components, but to their type, layout, fragmentation, strength and geometry, from which certain problems of structural response to earthquakes are derived. One of the greatest causes of damage to buildings has been the use of improper architectural-structural configurations.

Complexities in plan and vertical configuration are the main *architectural* factors of structural vulnerability *(1)*. Complexities in plan include the length of the building and complex plans (Fig. 2.1a). Long buildings are usually exposed to different excitation in different supports as well as to torsion or horizontal rotation resulting from ground movement. Owing to their use of complex plans, concentrations of stress are likely to appear in health facilities.

Vertical configuration problems are mainly determined by irregular vertical shapes. Setbacks in the volume of a building usually arise from urban design demands for illumination, proportion, etc. In seismic events, however, they are the cause of abrupt changes in stiffness and mass, producing a concentration of stress in the floors near the site of sudden change (Fig. 2.1b).

**Fig. 2.1. Samples of complex plans (a) and irregular vertical shapes (b)**



Configurations such as concentration of mass, short columns, soft storeys, lack of redundancy, excessive *structural* flexibility, flexibility of diaphragms and torsion are the main structural contributors to this vulnerability category.

### 2.2.3. Assessment of structural vulnerability

Building vulnerability is a measure of the damage a building is likely to experience when subjected to ground shaking of a specified intensity. The dynamic response of a structure to ground shaking is a very complex, depending on a number of interrelated parameters that are often very difficult, if not impossible, to predict precisely. These include: the exact character of the ground shaking the building will experience; the extent to which the structure will be excited by and respond to the ground shaking; the strength of the materials in the structure; the quality of construction, the condition of individual structural elements and of the whole structure; the interaction between structural and nonstructural elements; and the live load in the building at the time of the earthquake.

Various methods for assessing structural vulnerability exist that differ in cost and precision *(3–5)*. The type of method to be used depends on the objective of the assessment and the availability of data and technology (Fig. 2.2).

**Fig. 2.2. Methods for assessing structural vulnerability**

| | | | | | |
|---|---|---|---|---|---|
| expenditure | increasing computation effort → | | | | |
| application | building stock | | | individual building | |
| methods | observed vulnerability | expert opinions | simple analytical models | score assignment | detailed analysis procedures |

*Source*: Lang *(3)*.

In general terms, methods can be qualitative or quantitative. Qualitative methods are generally used to evaluate a large sample of buildings or to corroborate the level of safety in a given structure. Quantitative methods are utilized when the importance of the building merits it, or rather when qualitative methods have not been able to assess the safety of the building.

Score assignment methods are the best of the qualitative methods for identifying seismically hazardous buildings by exposing structural deficiencies. They often form the first phase of a multiphase procedure for identifying hazardous buildings, which must then be analysed in more detail to determine upgrading strategies. Potential structural deficiencies are identified from observed correlations between damage and structural characteristics. The scores for different deficiencies are usually calibrated by experts. Several score assignment methods have been developed, the most frequently used being those based on rapid visual screening *(6,7)*.

Detailed assessment procedures from the group of quantitative methods can be divided into linear (linear static and linear dynamic) and nonlinear (nonlinear static and nonlinear dynamic) procedures.

## 2.3. Nonstructural vulnerability

### 2.3.1. Background

It is often a case that seismic activity will cause insignificant damage to the structure of the health facility, yet its function will be impaired or disrupted because of damage to nonstructural elements. Even a low-magnitude seismic event can affect or destroy vital aspects of a hospital, i.e. those directly connected to its functions.

Experience shows that the secondary effects caused by damage to nonstructural elements can significantly worsen the situation. For example, ceilings and wall finishes can fall into corridors and stairways and hinder movement, while fires, explosions and leaks of chemical substances can be life-threatening. The functions of a hospital depend on such basic services as water, power and communications; damage to or interruption of these services can render a modern hospital virtually useless.

From a financial point of view, losses due to damage to nonstructural elements in a health facility are the most important since they represent some 85–90% of its total value.

Nonstructural hazards that can affect the life or health of the occupants of a hospital include furniture with sharp edges, glass that can fall in transit areas, objects that can fall from shelves, cabinets and ceilings, objects that can slide or roll along the floor, toxic or medical gases, corrosive or otherwise dangerous liquids, steam and fire, disconnection or failure of life-support systems, and inability to evacuate the building.

## 2.3.2. Nonstructural elements and causes of nonstructural damage

Nonstructural vulnerability of health facilities relates to three categories of nonstructural element (Table 2.1): architectural elements, installations, and equipment (medical and other) and furnishings.

**Table 2.1. Nonstructural elements in a health facility**

| Architectural elements | Installations | Equipment and furnishings |
|---|---|---|
| • Divisions and partitions | • Drinking-water | • Medical equipment |
| • Interiors | • Industrial water | • Industrial equipment |
| • Facades | • Steam | • Office equipment |
| • False ceilings | • Medical gasses | • Furnishings |
| • Covering elements | • Industrial fuel | • Supplies |
| • Cornices | • Vacuum network | • Clinical files |
| • Terraces | • Air conditioning | • Pharmacy shelving |
| • Chimneys | • Piping | • Laboratory shelving |
| • Glass | • Waste disposal | |
| • Attachments | | |
| • Ceilings | | |
| • Antennas | | |

*Source*: Pan American Health Organization *(1)*.

The design of any structure potentially subject to seismic action should take account of the fact that nonstructural elements must withstand the movement of the structure. Excitation of nonstructural elements caused by the movement of the structure is greater than excitation of the foundation of the building, which in many cases means that the safety of the nonstructural element is more compromised than that of the structure itself. In general, little attention is paid to these elements in the seismic design of structures, to the extent that many design codes do not include standards for nonstructural elements. This was evident in the case of recent earthquakes, whereby structures designed in accordance with modern seismic resistance criteria performed well while there was unfortunately poor performance by the nonstructural elements.

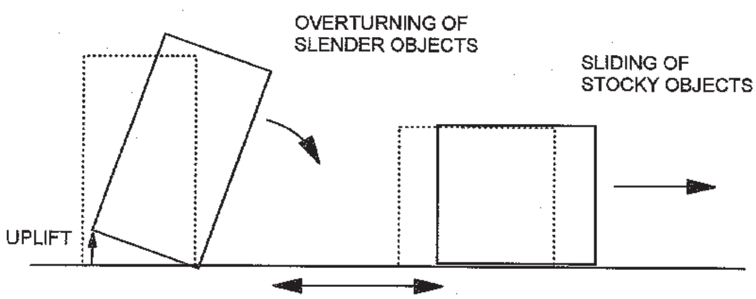
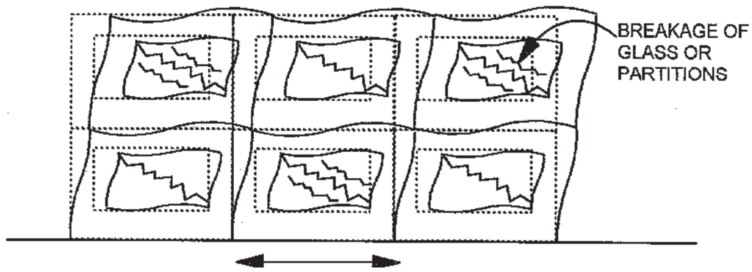
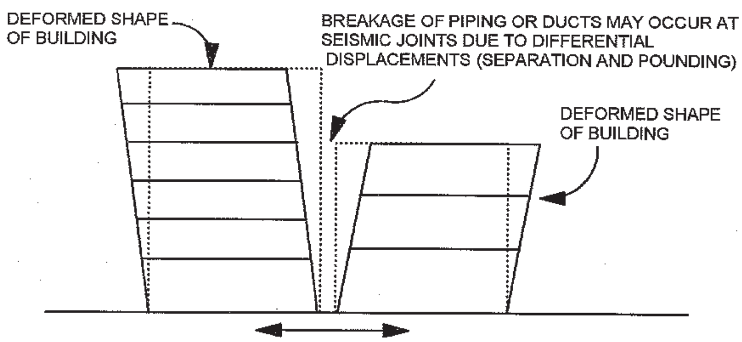
Ground shaking during an earthquake has three primary effects that cause damage to nonstructural elements in buildings (Fig. 2.3) *(8,9)*: (*a*) inertial or shaking effects on the nonstructural elements themselves; (*b*) distortions imposed on nonstructural components when the building structure sways back and forth; and (*c*) separation or pounding at the interface between adjacent structures.

## 2.3.3. Assessment of nonstructural vulnerability

Vulnerability assessment of nonstructural elements should be carried out after the assessment of structural vulnerability has been made, since the results of the latter are very valuable for judging the susceptibility to damage of nonstructural elements. For example, nonstructural elements may be affected by deformation of the main structure as determined by drift, the relative lateral movement between two storeys. Examples in this category would be partitions or other nonstructural elements between floors or placed between structural walls or columns.

When there is no direct interaction owing to deformation between the nonstructural element and the structural one, the nonstructural element is considered to be sensitive to acceleration. An example would be mechanical equipment

**Fig. 2.3. Effects of earthquakes on nonstructural elements**

| Seismic action | Effects on nonstructural elements |
|---|---|
| **INERTIAL FORCES** |  |
| **DISTORTIONS** |  |
| **SEPARATIONS** |  |

*Source*: Federal Emergency Management Agency *(8)*.

The most commonly used assessment procedures are those based on rapid visual screening, here classified as qualitative procedures. They comprise the following principal steps *(1)*:

1. formulation of a tentative list of components to be evaluated
2. inventory of number of components and location in the building
3. categorization of the seismic risk for each component
4. definition of a priority list in accordance with the priorities matrix
5. selection of assessment procedures for the priority components
6. quantitative assessment of the priority components.

The seismic risk is categorized into three levels: (1) risk of loss of life; (2) risk of loss of equipment and property; and (3) risk of functional loss.

To establish intervention priorities, two parameters are considered: the vulnerability of the element or system and the consequences of failure or malfunction of the element.

The vulnerability of the element or system is its susceptibility to damage, measured in terms of:

- characteristics of ground acceleration;
- response of the building to acceleration and displacement;
- size and weight of the element;
- location of the element in the building;
- resistance to the building's lateral stresses and relative stiffness of the component with respect to that of the building; and
- characteristics of the connection or joint (or lack of it) between the component and the structure or between the component and another nonstructural support element.

The consequences, or an estimate of the effect of the failure or damage to the component, are seen in terms of:

- location of the component in the building (according to the service or area); and
- occupation of the building or service and the possible impact on the occupants' lives or on the performance of the building or service should the element fail.

For more detailed nonstructural vulnerability assessment, other methods classified as quantitative are available. In this group of methods the assessment is performed using detailed computer models and nonlinear dynamic analysis, including interaction between structural and nonstructural elements. However, these are time consuming and expensive and require a high degree of analytical expertise to obtain reliable results. Consequently, they are to be used for detailed verification of the safety of nonstructural elements, including proposals for specific mitigation measures.

## 2.4. Administrative/organizational vulnerability

### 2.4.1. Background

The administrative and spatial organization of a complex health facility such as a hospital has to provide an optimal environment for performing diverse functions such as:

- outpatient-related functions
- diagnostic and treatment functions
- administrative functions
- service functions (food, supplies)
- research and teaching functions.

The range of medical services performed (Fig. 2.4) and the movement and communication of people, materials and waste during its day-to-day operation define the physical and administrative organization of the health facility.

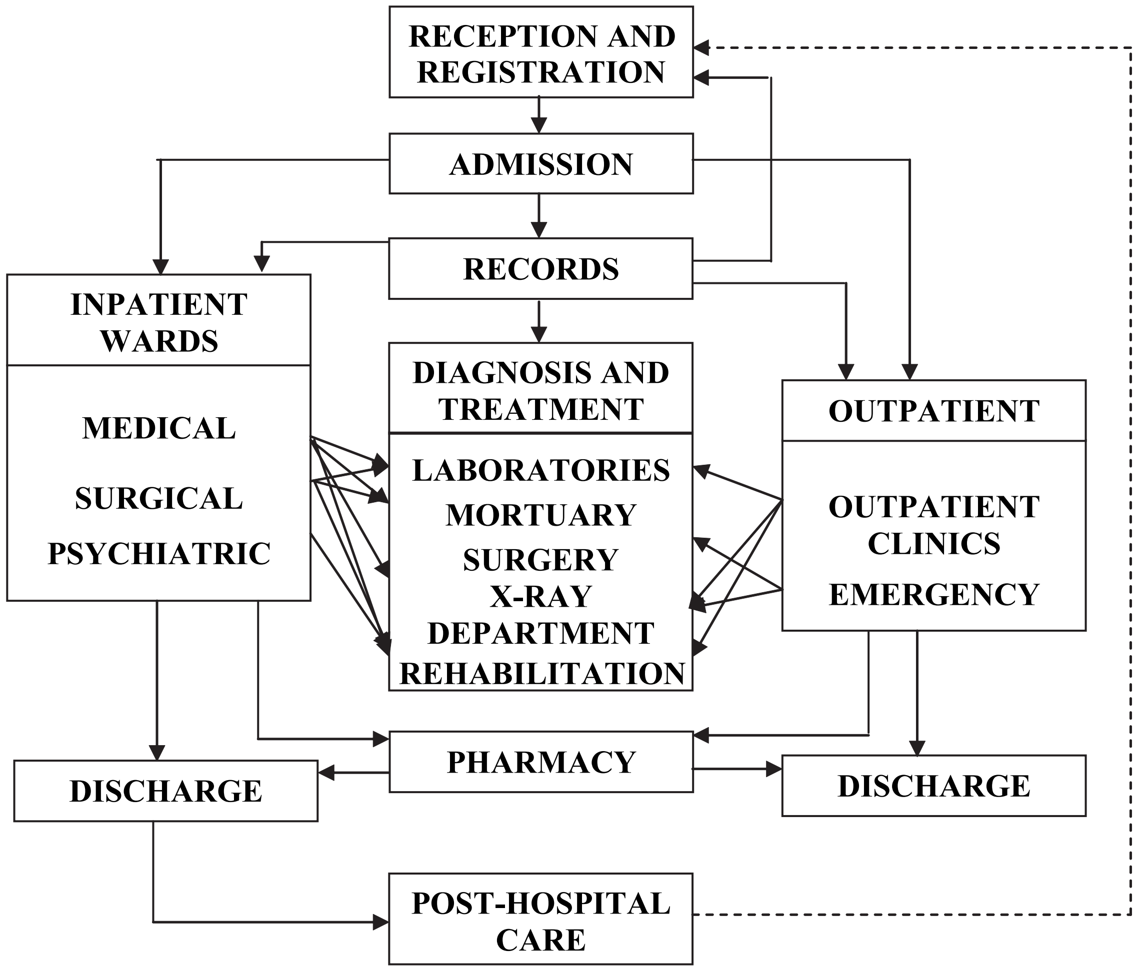
Administrative/organizational vulnerability depends on several factors *(1)*:

- distribution of architectural spaces and their relationship to the medical and support services provided inside the hospital;
- impact of this distribution on administrative processes such as contracting, procurement, maintenance, case management and internal and external communications; and
- physical and functional interdependence that link the different areas of a hospital.

The appropriate distribution and articulation of the spaces that make up a health facility can guarantee the continuity of the operations not only under normal conditions but also during emergencies and disasters, when the demand for health care is likely to be greatest.

Most hospital authorities have established formal disaster mitigation plans. Nevertheless, most of these plans fail to provide administrative and organizational alternatives in the event of severe damage to the facilities. A systematic approach that takes into account the fluid movement of staff, equipment and supplies in a safe environment during normal operation is vital for an effective response to disasters. This underscores the critical nature and interdependence of the various processes, buildings and equipment. Deficiencies in any of these areas can plunge a hospital into a crisis.

**Fig. 2.4. Major clinical relationships**




## 2.4.2. Administrative aspects

The first aspects that must be evaluated are the administrative, such as contracting, acquisitions and routine maintenance, as well as the physical and functional interdependence of the different areas of the facility. Also, administrative procedures related to infrastructure, including the resources that are supplied by public utility networks, such as communications and information systems, water supply and power supply, must be taken into account.

For the assessment of administrative procedures, the starting point must be the spatial-administrative relationships within the hospital and with its environment, including special agreements with public utility companies and suppliers in general *(1)*.

## 2.4.3. Organizational aspects

Many of the problems faced by a health facility in its day-to-day operation are due to its complex structure, comprising a number of interrelated functional parts. Continuous and smooth operation of such a complex system greatly depends on optimized organization of:

- personnel (number, professional skills, flexibility)
- equipment (availability, reliability, distribution, maintenance)
- material resources (availability, distribution)
- spatial organization.

In an emergency, these issues become even more important. Medical service procedures adopted in an emergency can be significantly different from normal procedures. It might be a good idea to create a general services function with special safety and operational procedures that can prevent the functional collapse of a health facility. Unsuitable spatial distribution of interrelated medical services can lead to disruption of services even if the structure has not suffered severe damage.

Internally, each of the services provided by the health facility will be of greater or lesser importance in the management of an emergency. In an emergency situation, the importance of medical services can be rated as (1) dispensable, (2) preferable, (3) necessary, (4) very necessary and (5) indispensable (Table 2.2) *(1)*.

**Table 2.2. Importance of typical hospital activities in an emergency**

| Clinical and support services | Importance rating |
|---|---|
| Trauma and orthopaedic | 5 |
| Intensive care unit | 5 |
| Urology | 5 |
| Emergency care | 5 |
| Sterilization | 5 |
| Diagnostic imaging | 5 |
| Pharmacy | 5 |
| Nutrition | 5 |
| Transport | 5 |
| Recovery | 5 |
| Blood bank | 5 |
| Outpatient consultation/admission | 4 |
| Paediatric surgery | 4 |
| Paediatrics | 4 |
| Laboratory | 4 |
| Haemodialysis | 4 |
| Laundry services | 4 |
| Internal medicine | 3 |
| Gynaecology and obstetrics | 3 |
| Administration | 3 |
| Neonatology | 3 |
| Respiratory medicine | 2 |
| Ophthalmology | 2 |
| Filing and case management | 2 |
| Dermatology | 1 |
| Psychiatry | 1 |
| Oncology | 1 |
| Otorhinolaryngology | 1 |
| Dental services | 1 |
| Therapy and rehabilitation | 1 |

*Source*: Pan American Health Organization *(1)*.

By definition, indispensable services require immediate logistical support, both in terms of human resources and basic supplies (water, power, food, medical supplies). If the emergency situation demands, noncritical services should be prepared to cede part or all of their personnel and even their facilities, so that the latter can be temporarily converted into additional emergency treatment areas in disaster situations. The institution must be capable of resolving any technical deficiencies that may arise, in the shortest possible time, and redirecting the necessary human and logistical resources towards the services that most urgently require them.

### 2.4.4. Assessment of administrative/organizational vulnerability

It is the duty of the authorities to assess the hospital's vulnerability to natural phenomena and obtain estimates of existing risk levels. In the case of administrative and organizational vulnerability, the assessment can start with a visual inspection of the facilities and the drafting of a preliminary report identifying key areas that demand attention, together with a study of administrative procedures, their critical points and their flexibility in emergency situations.

An assessment must be made of the following, which are critical for undisturbed operation of a health facility under both normal and emergency conditions.

- *Water and electrical power*. In order to perform their function properly and continuously, both under normal conditions and in emergency situations, health facilities depend on an uninterrupted supply of clean water and electrical power. In addition to the daily water supply system (usually provided by the public utility company), hospitals must have water storage tanks or other reliable backup source (e.g. on-site well) to ensure that clean water will be available in the event of an emergency. Health facilities must also be equipped with emergency generators that can start supplying power at any moment.
- *Communications*. The assessment should cover the service provider; a description, general state and location of the link-up; the number of line extensions and expansion capacity; and alternative communications systems through VHF/FM or other frequencies.
- *Roadway system*. The assessment should cover the capacity and general state of the main access routes, traffic patterns under normal and critical conditions, and pedestrian routes.
- *Processes*. These mostly have to do with the movements of people, equipment and supplies within the health facility. They also include routine administrative processes such as hiring, acquisitions, human resource management, and the flow of patients through the various clinical and support service areas of the facility.
- *Equipment*. Regular inspections and proper maintenance can ensure that key and costly hospital equipment remains in good working order.
- *Medical services*. This concerns patient service operations in the hospital, covering patient distribution and the services provided in each department (internal medicine, surgery, radiology, etc.). Medical services are dependent on time and spatial factors. During and immediately after a disaster, the types of medical service can be significantly affected by the destructive nature of the disaster. In some cases, even without any limitation of material supply, the operational capacity of a hospital may not be sufficient to meet the increased demand caused by the disaster. Medical service procedures adopted in an emergency situation can be significantly different from normal procedures; therefore, the input–output relationship established under normal operational conditions is no longer valid for assessment of emergency medical services.
- *Spatial distribution*. Proper spatial distribution will ensure accurate performance of a health facility not only under normal conditions but also in the event of an emergency. Unsuitable spatial distribution of interrelated medical services can lead to disruption of services, even if the structure has not suffered severe damage. Spatial distribution must be assessed on the basis of normal operations and their ability to respond to the massive need for emergency services, as well as the ability of other spaces to be adapted quickly to support the emergency services.

Depending on the kinds of parameters used to measure it, a health facility's functionality can be rated as good, average or poor or, where parameters are related to capability, as optimal, adequate, minimal or inadequate.

A qualitative vulnerability assessment can be performed by the health facility's personnel, since they best know their working environment, its good and weak points and the problems they encounter during the day-to day operation of the health facility.

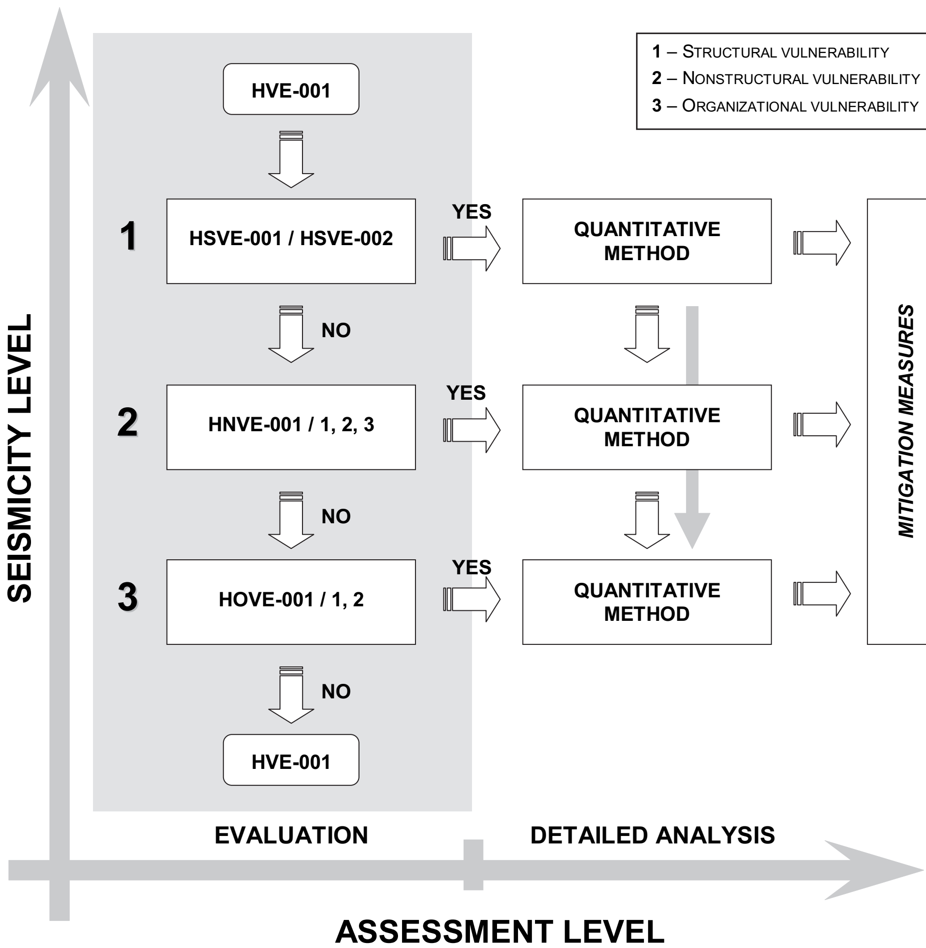
A more advanced and complex analysis of administrative/organizational vulnerability can be made through a systemic approach to the complexity of a health care facility. Mathematical modelling of interdependencies between various elements – physical (buildings, equipment, lifelines, patients, etc.), organizational (spatial distribution, personnel, material resources, etc.), institutional (public utilities, emergency services, local authorities, etc.) and environmental (location, access) – will yield quantitative indices for assessing the administrative/organizational vulnerability of the health facility.

# 3. HEALTH FACILITY INTEGRATED VULNERABILITY EVALUATION METHOD

## 3.1. Basis of the method

A new health facility integrated vulnerability evaluation (HVE) method is presented in this chapter (see Fig. 3.1). The method is designed to be suitable for hospital administrators in performing a preliminary (qualitative/quantitative) vulnerability assessment, identifying possible weak elements in the facility and main areas of vulnerability, and in determining priorities for necessary further "in-depth" investigations.

**Fig. 3.1. Structure of the HVE method**




The HVE method is a hybrid, mainly qualitative method using mainly rapid visual screening combined with the screener's judgement. The evaluation process depends on the seismicity level (Fig. 3.1). It combines separate evaluation methods for the three main vulnerability categories.

The rapid visual screening is based on a "sidewalk survey" of a building, using several data collection forms filled out by screeners. The collected data are processed and corresponding vulnerability indices, risk ratings or screener judgements are calculated or assigned in order to evaluate the facility according to structural, nonstructural and administrative/organizational vulnerability or performance. The vulnerability/performance interrelation matrix is presented in Table 3.1.

**Table 3.1. Vulnerability/performance interrelation matrix**

| | Rating | | |
|---|---|---|---|
| Vulnerability | Low | Moderate | High |
| Performance | Good | Average | Poor |

If a certain vulnerability category is assessed as moderate or high, a more detailed assessment should be performed using quantitative methods. If the structural vulnerability of a health facility is assessed as high, a detailed assessment is required for all vulnerability categories. Consequently, nonstructural and administrative/organizational vulnerability evaluations are also required to identify possible weak elements in the system. The administrative/organizational evaluation is applicable only to areas with low seismicity and can even be used during regular evaluations of the functioning of a health facility.

The HVE method takes account of features distinctive of Europe, such as the predominant building typology used for health facilities, and relies on existing vulnerability assessment methods and the European Macroseismic Scale (EMS-98) *(10)* for determining possible seismic demand.

The following data collection/evaluation forms are incorporated in the HVE method (Fig. 3.1; see also Annex 1):

- HVE-001: general vulnerability evaluation;
- HSVE-001 and HSVE-002: structural vulnerability evaluation;
- HNVE-001/1, HNVE-001/2 and HNVE-001/3: nonstructural vulnerability evaluation; and
- HOVE-001/1 and HOVE-001/2: administrative/organizational vulnerability evaluation.

Successful completion of the vulnerability evaluation requires appropriate cost estimation and budget development for all its phases: pre-field, field screening and post-field.

Pre-field planning should include the following activities:

1. selection and review of the data collection and evaluation forms
2. determination of the seismicity of the site
3. information on local ground conditions
4. review of the design and construction documents (if in existence)
5. information on the level of seismic preparedness
6. the qualifications of and training for screeners.

## 3.2. General vulnerability evaluation

The general vulnerability evaluation of a health facility is performed using Form HVE-001 (Annex 1). The form has three sections: (*a*) general data on the facility; (*b*) information on its seismic exposure and preparedness; and (*c*) the performance of the facility.

### 3.2.1. General data

This section includes information on:

- the location of the facility, such as municipality, city, name and address;
- the type of facility (size, position in the health care system, types of function, etc.) such as hospital, polyclinic and health care centre;
- the identification (ID) number of the facility in case several facilities are being evaluated;
- the site area of the facility, including the built area; and
- the number of staff employed and the capacity of the health facility.

### 3.2.2. Seismic exposure and preparedness

This section includes information on:

- the seismic exposure of the facility in terms of maximum observed intensity and seismic zoning; and
- the seismic preparedness level of the facility by checking the existence of emergency response plans, supplies, response training and drills.

The maximum observed intensity in fact represents the maximum regional intensity expressed in terms of EMS-98.

The seismic zoning of the region where the facility is located (if this exists) is to be expressed in terms of seismic intensity (I), peak ground acceleration (PGA) or spectral values for seismic action with a 475-year return period (10% probability of occurrence in a 50-year period) (see Annex 4). The PGA–I conversion can be accomplished using the relationship $\log(PGA) = 0.25\,I + 0.25$.

### 3.2.3. Health facility performance

The third part of the form comprises a general evaluation of the facility's structural, nonstructural and administrative/organizational performance, rating it as good, average or poor; in it fact summarizes the separate vulnerability evaluations.

At the end of the form space is provided for the names of the screeners and the date of the evaluation.

## 3.3. Structural vulnerability evaluation

The structural vulnerability evaluation is performed using Forms HSVE-001 and HSVE-002 (see Annex 1) for every building in the facility *(6,11)*. Form HSVE-001 is applicable to masonry buildings and Form HSVE-002 to reinforced concrete buildings. The forms contain sections covering general building data, occupancy load, soil type, existing damage and vulnerability indices/modifiers.

### 3.3.1. General building data

This section includes information on:

- number of buildings (if the facility contains several buildings)
- year of construction
- building type
- number of storeys
- total building area
- building function.

The year of construction is important for reinforced concrete buildings in determining the level of aseismic protection.

The subsection on building type includes identification of the principal bearing system of the building. Two predominant groups of construction are encountered in European health facilities: masonry and reinforced concrete. According to the European building typology matrix *(12)*, within each group the following predominant building types are found (see Annex 2).

*Masonry buildings*

M1.2 – simple stone masonry buildings
M3.1 – unreinforced masonry buildings with wooden floors
M3.4 – unreinforced masonry buildings with reinforced concrete floors
M5 – overall strengthened masonry buildings.

*Reinforced concrete buildings*

RC1 – reinforced concrete moment-resistant frame buildings
RC2 – reinforced concrete shear wall buildings

RC3.1 – buildings with reinforced concrete frames with regularly distributed unreinforced masonry infill walls
RC3.4 – buildings with irregular reinforced concrete frames
RC4 – reinforced concrete dual-system buildings
RC5 – buildings of precast concrete tilt-up walls
RC6 – buildings of precast concrete frames with concrete shear walls.

If a building comprises more than one structural type, the weakest one should be considered when making a vulnerability assessment.

Buildings are classified into three height categories according to the number of storeys *(12)*:

- masonry buildings: low-rise (1–2 storeys); mid-rise (3–5 storeys); high-rise (6+ storeys); and
- reinforced concrete buildings: low-rise (1–3 storeys); mid-rise (4–7 storeys); high-rise (8+ storeys).

The total building area is the gross area.

The building function refers to the health services performed in the building.

This section also includes sketches of the plan and elevation and a photograph of the building.

### 3.3.2. Occupancy load

Information about occupancy load is important in setting priorities for earthquake mitigation plans. Occupancy load information is directly associated with the data provided under general data in Form HVE-001 in the sections on employees and capacity.

### 3.3.3. Soil category

Determination of the soil category where the health facility is located is crucial, since this factor plays an important role in vulnerability evaluation through the selection of appropriate vulnerability index modifiers. According to Eurocode 8 (EC-8) there are three categories of soils (Table 3.2) *(13)*.

**Table 3.2. Soil categories defined by EC-8**

| Soil category | Description |
|---|---|
| A. Rock/hard soil conditions | Rock or other geological formation characterized by a shear wave velocity (Vs) of at least 800 m/s, including at most 5 m of weaker material at the surface.<br><br>Stiff deposits of sand, gravel or overconsolidated clay, at least several tens of metres thick, characterized by a gradual increase in mechanical properties with depth and by Vs values of at least 400 m/s at a depth of 10 m. |
| B. Medium soil conditions | Deep deposits of medium dense sand, gravel or medium stiff clays with a thickness of from several tens to many hundreds of metres, characterized by a Vs value of at least 200 m/s at a depth of 10 m increasing to at least 350 m/s at a depth of 50 m. |
| C. Soft soil conditions | Loose, cohesionless soil deposits with or without some soft cohesive layers, characterized by Vs values below 200 m/s in the uppermost 20 m.<br><br>Deposits with predominant soft-to-medium stiff cohesive soils, characterized by Vs values below 200 m/s in the uppermost 20 m. |

Information on soil conditions should be gathered from the design documentation of the health facility or be determined by an expert. If there is no possibility of determining the soil category, it is recommended that a conservative approach be taken by adoption of category C.

### 3.3.4. Existing damage

Information on existing damage or previous interventions in the building is required to define vulnerability index modifiers regarding building maintenance and retrofitting work.

### 3.3.5. Vulnerability indices/modifiers

The section on vulnerability indices and modifiers is the most important and the only section that is different in the two HSVE forms, since different vulnerability modifiers are assigned to masonry and reinforced concrete buildings. The proposed basic vulnerability indices for every building type and the vulnerability modifiers for masonry and reinforced concrete buildings are taken from the RISK-UE WP4 LM1 method *(4,5,14)* adapted to health facility characteristics.

The vulnerability modifiers are the same for all masonry building types. The vulnerability indices for reinforced concrete buildings depend on the construction period. Three periods are introduced and in general represent (*a*) the no-code to low-code period (*b*) the medium-code period and (*c*) the high-code period. In the forms the following three periods are proposed: before 1970, 1970–1980 and after 1980. These are approximate, however, and will be different for each country according to the introduction of the local aseismic design codes.

### 3.3.6. Determining the structural vulnerability level

Determination of the vulnerability level starts with calculation of the total vulnerability index as a sum of the basic vulnerability index and the corresponding vulnerability modifiers. The expected damage states of the building can be calculated using the expression:

$$\mu_D = 2.5\left[1 + \tanh\left(\frac{I + 0.125\ TV_I - 13.1}{2.3}\right)\right]$$

where $\mu_D$ is the mean damage grade, I is the EMS-98 seismic intensity and TVI is the total vulnerability index *(4,14)*. A description of the EMS-98 damage grades for masonry and reinforced concrete buildings is given in Annex 3.

The vulnerability level is estimated according to the ranges of the total vulnerability index given in Table 3.3 and Fig. 3.2, and the corresponding performance according to Table 3.1. Detailed structural vulnerability assessment will be required if the estimated level of structural vulnerability is moderate or high.

## 3.4. Nonstructural vulnerability evaluation

The nonstructural vulnerability evaluation is performed using Forms HNVE-001/1, /2 and /3 (Annex 1) for every building in the facility (1,8,9). Form HNVE-001/1 applies architectural elements, Form HNVE-001/2 to equipment and furnishings and Form HNVE-001/3 to basic installations and services. The proposed evaluation is compatible with FEMA-74 and PAHO 2000 methodologies and is based on estimating the expected nonstructural vulnerability and consequences *(1,8)*. The forms contain sections covering building number (if the facility comprises more than one building, type of nonstructural element, seismic intensity, type of risk and priority.

Information on seismic intensity is connected to the section on seismic exposure in Form HVE-001. The EMS-98 seismic intensity (I) is considered low if I <5, moderate if I = 5–8 and high if I >8.

### 3.4.1. Nonstructural risk ratings

The following types of risk are considered *(1,8)*.

- *Life safety (LS)* risk: the risk of being injured by the item. This does not include the overall impact on safety systems in a building, such as loss of emergency power in a hospital or loss of fire detection capability. These disruptions of service are covered under loss of function below.
- *Property loss (PL)* risk: the risk of incurring a repair or replacement cost because of damage to the item. This property loss, as used here, includes the cost of mending a broken pipe but not the indirect cost of damage due to leaked water, and includes the cost of repairing a computer but not any loss of business revenue due to computer downtime. These indirect effects cannot be estimated here on a generic basis.
- *Loss of function (LF)* risk: the risk that the item will not function because it has been damaged. This includes some consideration of the impact of this loss of function of the component on the operation of an ordinary occupancy building. Not included are off-site effects, such as the loss of function of a piece of equipment because of a city-wide power cut. Losses of power, water and other utilities are real problems to consider but are outside the scope of the item-by-item ratings here.

**Fig. 3.2. Expected damage grade and vulnerability vs total vulnerability index**

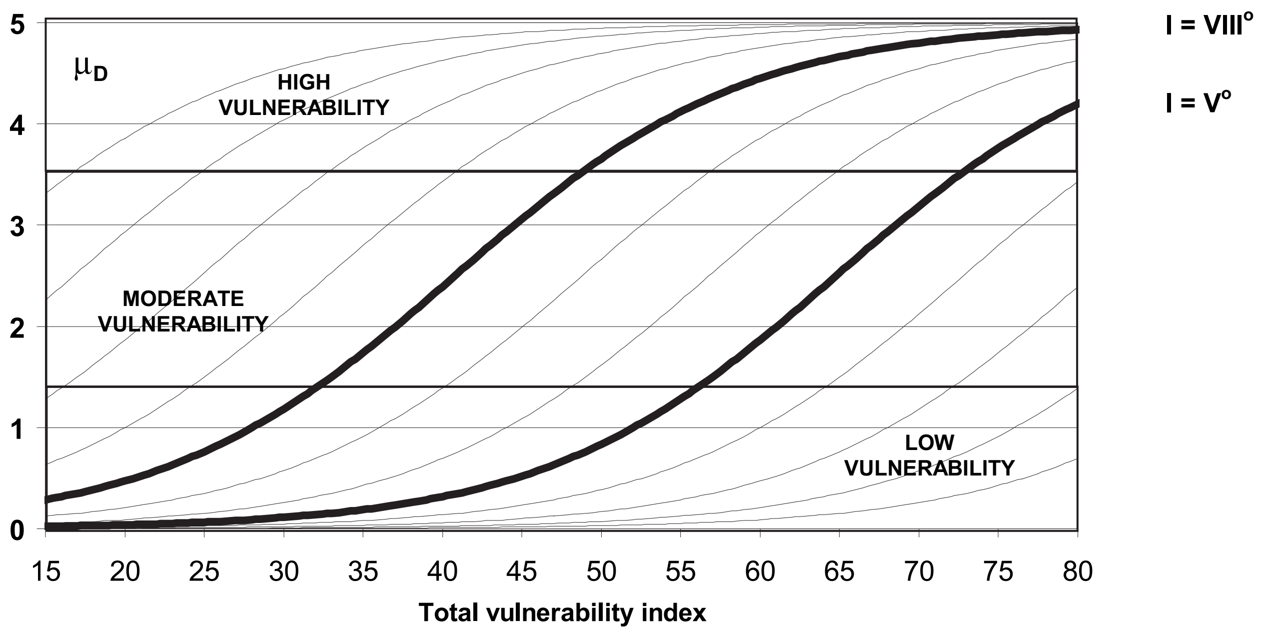



**Table 3.3. Ranges of the total vulnerability index**

| Seismic intensity | Vulnerability level | | |
|---|---|---|---|
| | Low | Moderate | High |
| 1 | < 89 | 89–105 | > 105 |
| 2 | < 81 | 81–97 | > 97 |
| 3 | < 73 | 73–89 | > 89 |
| 4 | < 65 | 65–81 | > 81 |
| 5 | < 57 | 57–73 | > 73 |
| 6 | < 49 | 49–65 | > 65 |
| 7 | < 41 | 41–57 | > 57 |
| 8 | < 33 | 33–49 | > 49 |
| 9 | < 25 | 25–41 | > 41 |
| 10 | < 17 | 17–33 | > 33 |
| 11 | < 9 | 9–25 | > 25 |
| 12 | < 1 | 1–17 | > 17 |

The vulnerability of the facilities and equipment (PL risk type) can be divided into three categories:

- *low (L) vulnerability*: the evaluated component is reasonably well anchored and there is a low probability that it would be damaged when faced with the design forces and deformation of the building;
- *moderate (M) vulnerability*: the component is anchored, but there is a moderate probability of this fixture failing when faced with the design forces and deformation of the building; and
- *high (H) vulnerability*: the component lacks fastenings or the fastening is inadequate or incorrect, leading to a high probability of damage when faced with the design forces and deformation of the building.

The consequences (LF risk type) may also be divided into three categories:

- *low (L) consequences*: owing to its location in the building or to its type, damage to the component will probability not causing injury to the occupants or interfere with the performance of the facility;
- *moderate (M) consequences*: owing to its location or to its type, damage to the component represents a moderate probability of causing injury to the occupants or of interfering with the performance of the facility; and
- *high (H) consequences*: damage to the component will very probably cause injury (and even death) of the occupants, or seriously compromise the performance of the facility.

Forms HNVE-001/1, /2 and /3 propose risk ratings for the principal groups of nonstructural elements only. These ratings are based on FEMA 74 (8) but modified to suit health facility building occupancy. For a more detailed evaluation it would be necessary to propose different ratings based on those given.

The risk ratings are also based on the assumption that the item has been installed without seismic bracing, anchorage, restraint or allowance for differential movements. Another assumption is that the item is to be located at or near the ground level or in a low-rise building.

The priority can be determined using the priority matrix given in Table 3.4.

**Table 3.4. Priority matrix**

| Vulnerability | Consequences | | |
|---|---|---|---|
| | High | Moderate | Low |
| High | 1 | 4 | 7 |
| Moderate | 2 | 5 | 8 |
| Low | 3 | 6 | 9 |

*Source:* Pan American Health organization *(1)*.

## 3.4.2. Determining the nonstructural vulnerability/consequences level

The first step in determining the nonstructural vulnerability/consequences level is to calculate the total PL (TPL) and total LF (TLF) scores using the following formulas (Annex 1):

$$TPL = \frac{[NL \times (1) + NM \times (2) + NH \times (3)]}{} \qquad TLF = \frac{[NL \times (1) + NM \times (2) + NH \times (3)]}{}$$

where NL, NM and NH are the number of L, M and H risk ratings, respectively, for the corresponding seismic intensity and group of nonstructural elements; (1), (2) and (3) are weighting factors; and NE is the number of the elements under consideration.

The vulnerability/consequences level is determined according to the ranges of TPL or TLF values given in Table 3.5 and Annex 1.

**Table 3.5. Vulnerability/consequences level**

| | Low | Moderate | High |
|---|---|---|---|
| Vulnerability level (TPL) | 1–1.7 | 1.7–2.3 | 2.3–3 |
| Consequences (TLF) | 1–1.7 | 1.7–2.3 | 2.3–3 |

## 3.5. Administrative/organizational vulnerability evaluation

The administrative/organizational vulnerability evaluation is performed using Form HOVE-001/1 and /2 (Annex 1), which together have three sections covering capability assessment, spatial distribution of services and external interdependence (lifelines). Evaluation of parameters is qualitative (Table 3.6) using the following ratings *(1)*:

- good: the parameter under review satisfactorily meets current local standards in disaster reduction and there is no need to modify it;
- average: the parameter under review satisfies local standards only moderately and a minor modification could improve performance significantly; and
- poor: the parameter under review does not meet local standards and must be modified substantially to resolve this deficiency.

**Table 3.6. General assessment of organizational parameters**

| | Rating | | |
|---|---|---|---|
| Capability assessment | High | Moderate | Low |
| Spatial distribution | Good | Average | Poor |
| Access to facility | Good | Average | Poor |
| Electrical power | Good | Average | Poor |
| Water supply | Good | Average | Poor |
| Communication | Good | Average | Poor |
| Lifelines maintenance | Good | Average | Poor |

Administrative/organizational vulnerability evaluation is subjective, based on the knowledge and experience of the medical staff who are faced with all problems that may arise during the operation of the health facility. Administrative/organizational vulnerability is evaluated for the entire health facility (system level).

### 3.5.1. Capability assessment

This section considers the assessment of the allocation of resources and personnel to the various medical services existing at the health facility. Four parameters define the capability of each of the medical services:

- assigned personnel
- emergency supplies
- medical equipment
- backup systems.

Each of these parameters, corresponding to the ability of the medical service to fulfil its tasks under both normal and emergency conditions, is rated according to the following scale.

1. *Optimal*: efficient allocation of resources and personnel.
2. *Adequate*: acceptable allocation of resources and personnel; operation can proceed normally.
3. *Minimal*: barely acceptable allocation of resources or personnel; operation can proceed with certain restrictions.
4. *Inadequate*: unacceptable assignment of resources or personnel; severe limits on the service in question or impossibility of carrying out the service in question.

The overall capability of the health facility to meet its operational demands under normal and emergency conditions is shown by the ratings given to the medical services with an importance index of 5, 4 or 3, since those services are the most important, especially in case of emergency.

An overall capability rating of "high" means that all medical services with an importance index of 5 or 4 must have all parameters rated 1 or 2. Those with an importance index of 3 can have an occasional rating of 3. If any of the parameters related to services with an importance index of 5 or 4 are rated 3 (minimal) or 4 (inadequate), the overall capability of the health facility is rated "moderate" or "low".

### 3.5.2. Spatial distribution of services

The medical services interrelation matrix defines the level of interdependence between the various services. Assessment is performed using the general hospital ground plan to define the spatial distribution of closely related services (categories 3 and 4) existing at the health facility, thus evaluating the quality of the spatial distribution of services.

### 3.5.3. External interdependence

The third part of the form relates to the lifelines systems essential for the functioning of the health facility:

- *Access to the hospital complex*: vehicle and pedestrian access, access for the staff and the public and air access, if available, in the form of a heliport.
- *Power supply*: assessment of regular/backup supply system and the capacity of the backup system (partial or full operational load).
- *Water supply*: assessment of the reliability of the regular supply system, the backup system, and water capacity and quality.
- *Communication*: internal and external communication and alternative lines of communication (radio connection).

The overall rating of critical lifelines (power supply, water supply and communications) depends on the existing backup systems. For example, if the water supply backup system comprises only a reservoir or well without water treatment, than the overall rating of this lifeline is average. The same applies to a power supply backup that provides only partially for power needs.

# 4. SEISMIC RISK MITIGATION STRATEGIES

## 4.1. Reducing structural vulnerability

Building codes in themselves cannot guarantee safety from excessive damage, since codes are rules that establish minimum requirements and are continually updated in accordance with technological advances and lessons learned through research and study of the effects of earthquakes. Ductility (i.e. energy absorption capacity) and structural redundancy have proven to be the most effective means of providing safety against collapse, especially if the movements are more severe than those anticipated by the original design. Severe damage or collapse of many structures during major earthquakes is, in general, a direct consequence of the failure of a single element or series of elements with insufficient ductility or strength.

Building codes primarily regulate the design and construction of a building's structural system – the elements that provide support to the building. Good performance of the structural system during an earthquake does not necessarily mean, however, that there will not be considerable damage to the building, injury or even loss of life. Nevertheless, poor performance of the structure will most certainly result in heavy property damage, injury and loss of life.

It is almost half a century since criteria for constructing earthquake-resistant buildings were incorporated into building codes and enforced worldwide. To ensure that health facilities perform as expected during and after an earthquake, current design strategies for new ones are more rigorous, not only from a structural but also from a functional point of view. A high percentage of existing health facilities were built decades ago, with earthquake-resistant criteria that, by today's standards, are obsolete.

To ensure the functioning of health facilities, new earthquake-resistant design requirements increase the number and dimensions of structural elements. This means that the structural systems of buildings are more expensive. However, even if the support capacity of a structure to resist an earthquake is doubled or tripled, the total cost of the structure will rise by less than 8%. Since typically the structure itself represents only 12–18% of the total cost of building a hospital, including equipment, the final cost of ensuring its ability to function during an emergency would not exceed 1–2% of the final costs.

Many existing health facility buildings do not comply with the necessary technical requirements to ensure continued functioning after an earthquake. Their vulnerability can greatly exceed currently accepted levels. Experience shows, however, that the safety of existing structures can be improved by applying appropriate mitigation measures. These should consider the occupation characteristics of the facility and, in accordance with the current engineering requirements of each country, be carried out to reduce risk and guarantee adequate performance.

Assessing the condition of an existing building may raise serious doubts about its ability to withstand seismic events. This can lead to the need for retrofitting or total or partial rehabilitation of the building, in order to reduce its vulnerability before an event occurs. This is mandatory for buildings providing the essential services that respond to emergencies caused by earthquakes.

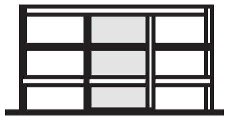
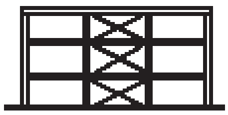
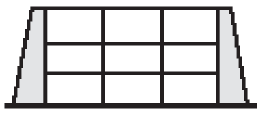
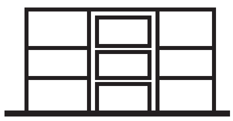
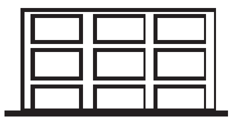
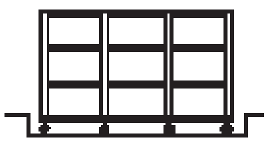
The execution of proper retrofitting measures should consider the following aspects *(1)*.

- *Physical and functional aspects*. Retrofitting should not affect the hospital's day-to-day operations.
- *Structural safety*. It is essential to reduce vulnerability to acceptable levels, so that the hospital can continue to function after an earthquake.
- *Construction techniques*. Retrofitting should be carried out using construction techniques that have the least impact on the normal functions of the hospital, since it would be difficult to shut it down for repairs.
- *Costs*. The cost of retrofitting cannot be ascertained unless a detailed design of the structural solution and of its implications for the nonstructural elements is carried out. Retrofitting costs are usually relatively high, especially when done in a short period of time. Nevertheless, if the work is done in stages, costs can be maintained within the normal range of expenditure for hospital maintenance.

Interventions should seek to reduce vulnerability by responding to existing performance problems. Structural retrofitting should therefore (*a*) increase resistance, (*b*) increase stiffness and therefore reduce deformation, (*c*) increase ductility and (*d*) attain an adequate distribution of stress between the different resistant elements, as much in the ground plan as in the vertical configuration.

The usual systems of structural reinforcement and the possible benefits are presented in Table 4.1.

**Table 4.1. Conceptual solutions for reducing structural vulnerability**

| Reinforcement measure | Diagram | Benefits |
|---|---|---|
| Interior walls |  | Increased resistance and reduced drift |
| Addition of diagonal bracing |  | Increased resistance and reduced drift |
| Addition of buttresses |  | Confinement and reduced drift |
| Addition of interior or exterior moment-resistant frame |  | Confinement and reduced drift |
| Complete rebuilding |  | High seismic resistance capacity and control of typical types of damage |
| Base isolation |  | Protection of building through control of shaking |

*Source*: Pan American Health Organization *(1)*.

Reducing the seismic vulnerability of a health facility is usually more complex than for other types of facility. Some of the reasons for this are that:

- buildings cannot normally be vacated during retrofitting;
- scheduling of the work must take into account the operation of the different health services so as not to cause serious disruptions;
- a wide variety of unforeseen tasks can be expected owing to the difficulty of precisely identifying details of the construction process before the work begins; and
- the effects of structural modifications on nonstructural elements and on architectural finishes must be identified before work starts.

Consequently, the development of a retrofitting project should follow a very detailed work plan that addresses the functioning of the health services at each step of the process. In the same way, the plan should establish proper coordination with administrative, medical service and maintenance personnel.

## 4.2. Reducing nonstructural vulnerability

The importance of the failure of nonstructural building components during earthquakes has generated worldwide concern in recent years. Experience is well documented of cases where the building structure has survived an earthquake with no damage but the facility is rendered unusable owing to extensive nonstructural damage and damage to equipment and building lifelines. Risks to the lives and safety of the occupants of the building from failure of the nonstructural components can be considerable, even when the structure of the building has performed well. The cost of nonstructural damage and damage to equipment and building lifelines is also far greater than previously expected. This is particularly pertinent in health facilities, where the cost ratio of the nonstructural elements, medical equipment and specialized facilities to the total cost of the building amounts to between 85% and 90%.

To reduce nonstructural vulnerability, a disaster mitigation plan for the facility must be developed with the involvement of the hospital director, the chief administrator, the head of maintenance, the head of clinical and support services and professionals who are experts in applying mitigation measures. It may be appropriate to include other professionals on the team, depending on the type of project being undertaken.

Once a nonstructural element has been identified as a potential threat and its priority established in terms of loss of life, property and/or function, the appropriate measures must be adopted to reduce or eliminate the hazard. Twelve mitigation measures that have been effective in many cases are listed below *(1,15)*.

### 4.2.1. Mitigation measures

*Removal* is probably the best mitigation option in many cases. An example is a hazardous material that could be spilled but could be stored perfectly well outside the premises. Another solution would be the use of better fastenings or stronger supports, but the most effective solution would be removal and replacement.

*Relocation* would reduce danger in many cases. For example, a very heavy object on a top shelf could fall and seriously injure someone, as well as breaking and being expensive to replace. If moved to a floor-level shelf it would not represent any danger to human life or property.

*Restricting the mobility* of certain objects such as gas cylinders and power generators is a good measure. It does not matter if the cylinders move, so long as they do not fall and their valves remain intact. Backup power generators are sometimes mounted on springs to reduce the noise and vibration during operation, but these springs would amplify ground motion. Restraining supports or chains should therefore be placed around the springs to keep the generator from moving or being knocked off its stand.

*Anchorage* is the most widely used precaution. It is a good idea to use bolts, cables or other materials to prevent valuable or large components from falling or sliding. The heavier the object, the more likely it is that it will move during an earthquake. A good example is a water heater, of which there will probably be several in a hospital. These are heavy and can easily fall and break a water main. A simple solution is to use metal straps to fasten the lower and upper parts of the heater against a firm wall or another support.

*Flexible couplings* are sometimes used between buildings and outside tanks, between separate parts of the same building, and between buildings. They are used because the separate objects each move independently in response to an earthquake: some move quickly, others slowly. If there is an outside tank joined to the building by a rigid connecting pipe, the tank will vibrate at frequencies, directions and amplitudes that are different to those of the building and will cause the pipe to break. A flexible pipe between the two would prevent ruptures of this kind.

*Supports* are suitable in many cases. For example, ceilings are usually hung from cables that only withstand the force of gravity; when subjected to the horizontal stresses and torsion of an earthquake, they easily fall. They can cause serious injury to people underneath them and obstruct evacuation routes.

*Substitution* by something that does not represent a seismic hazard is appropriate in some situations. For example, heavy tiles not only make the roof of a building heavy but also more susceptible to the movement of an earthquake.

The individual tiles tend to come off, creating a hazard for people and objects alike. One solution would be to replace the tiles with a lighter, safer roofing material.

*Modification* is a possible solution for an object that represents a seismic hazard. For example, earth movements twist and distort a building, possibly causing the rigid glass in the windows to shatter and launch glass splinters onto the occupants and passers-by. Transparent adhesive plastic covering the inside surface of the glass prevents it from shattering.

*Isolation* is useful for small, loose objects. For example, if side panels are placed on open shelves or cabinets are provided with doors and latches, their contents will probably not be thrown around the room if an earthquake occurs.

*Reinforcement* is feasible in many cases. For example, an unreinforced infill wall or a chimney may be strengthened, at no great expense, by covering the surface with wire mesh and cement.

*Redundancy* or duplication of items is advisable. Emergency response plans that call for additional supplies ensure a certain level of independence from external deliveries, which could be interrupted in the case of an earthquake.

*Rapid response and repair* is a mitigation measure used on large oil pipelines. Where it may not always be possible to prevent the rupture of a pipeline in a given place, spare parts are stored nearby and arrangements are made to enter the area quickly in case a pipe breaks during an earthquake. A hospital should have spare plumbing, power and other components on hand, together with the appropriate tools, so that repairs can easily be made. For example, water pipes may break during an earthquake; it may be impossible to take prior measures to totally eliminate this risk, but it should be possible to ensure that everything necessary for quick repair is at hand. With prior earthquake planning, it is possible to save enormous water damage costs with a minimum investment in a few articles.

These general measures are applicable to almost all situations. In many cases, however, it is enough to be creative and to devise one's own way of mitigating the effects of disasters.

### 4.2.2. Mitigating damage to equipment and furnishings

Today, objects and equipment inside hospitals are of great value, surpassing even the cost of the building. Most of these elements, including supplies, are essential for saving lives and can represent a danger in the event of an earthquake. Listed below are some these elements and the possible mitigation measures to be undertaken in health facilities *(1,15)*.

*Essential diagnostic equipment*. Phonendoscopes, tensiometers, thermometers, otoscopes, ophthalmoscopes, reflex hammers and flashlights should always be available for physicians, paramedics and administrative staff. Additional stocks are required for emergency situations. Such stocks should be located in an easily accessible place and clearly labelled in such a way that they can be easily located after a disaster by support personnel, volunteers, first aid units, etc.

*Beds for patients*. The possibility has already been mentioned of locating extra beds in rooms, vestibules, visiting rooms, solariums, inpatient areas, etc. This will not be possible if there is not a supply of beds, mattresses, etc., for emergencies. It is also necessary to protect both beds and patients from movement during an earthquake. Beds and other equipment should be secured and at the same time easy to move.

*Carts*. Carts used to convey special equipment for crisis intervention and are very important in saving lives and storing supplies. They are found in all patient care areas. The objects they contain should be fastened to the carts, and when they are not in use they should be folded up and placed against dividing walls.

*Respirators and suction equipment*. This equipment should be fastened in such a manner as to guarantee that it does not become disconnected from patients.

*Hazardous substances*. Many products used in hospitals can be hazardous if released or spilled. Shelves containing drugs or chemicals, if overturned, can constitute a threat by virtue of the toxicity, either liquid or gaseous, of the chemicals. On many occasions fires are started by the action of chemicals, overturned gas cylinders, or breaks in gas supply lines.

*Monitors*. Monitors are often stacked, placed on pieces of furniture or on carts, or attached to the wall. It is necessary to fasten each module to the wall or the shelf on which it is located.

*Surgery tables*. In the great majority of cases these tables are anchored, and therefore movement is minimal. Special care should be taken in fastening patients, since most problems arise from the auxiliary equipment around the table, such as anaesthesia equipment, respirators, carts, etc., all of which should be firmly secured.

*Filing cabinets*: In most cases filing cabinets contain clinical histories and a great quantity of information necessary for providing appropriate care to patients. Filing cabinets should be secured to the floor and walls in order to avoid possible overturn. The drawers of such cabinets, which slide on ball bearings, may open rapidly during an earthquake unless they are firmly secured from the outside.

*Computers*: Much of a hospital's general information is contained in computers. They should be well secured to desks to avoid their falling and losing their ability to function. Computer services should take into account the recommendations made for networks, which can be supported by an emergency plant.

*Refrigerators*. It is particularly important during emergency situations that the blood bank refrigerator continues to function properly, and consequently it should be connected to the emergency power supply.

*Nuclear medicine*. This sector involves particularly hazardous situations, given the type of equipment and materials it uses.

- Collimator cars weigh some 700 kg and should thus be firmly fastened when transported.
- Gamma chambers are also quite heavy and are provided with wheels. They require collimators. When they are not in use they should be kept in the lowest positions.
- Oil baths are found in the nuclear pharmacy. They normally consist of an open tank containing hot oil, which should be fastened to a shelf and covered in order to prevent splattering.
- Shielding screens are generally composed of lead bricks, which should be joined together so that vibration will not displace them.

Radioactive materials are extremely hazardous. This is particularly true of waste materials, whose radioactivity must not be ignored. They should be stored in airtight canisters.

## 4.3. Reducing administrative/organizational vulnerability

Of all the elements that interact in the day-to-day operations of a health facility, the administrative and organizational aspects are among the most important in ensuring its continuous operation in normal conditions and even more so after an earthquake or other catastrophic event.

To reduce administrative and organizational vulnerability, recommendations must be made regarding efficient spatial distribution and interaction, both under normal conditions and when the number of victims exceeds the everyday capacity of the hospital. These recommendations must include solutions to help improve the internal and external functioning of the services provided by the hospital in the event of an emergency *(1)*.

The duty of the authorities is to assess a health facility's vulnerability and obtain estimates of existing risk levels. Once the analysis is complete, the information gathered should be used to determine what level of risk is acceptable and what measures are to be undertaken in order to improve functionality under normal end emergency conditions, for example:

- optimize the use of available space and the spatial distribution of interrelated medical services;
- continually improve the quality of services, which will automatically lead to improvements in day-to-day administrative and organizational operation, leading to a hospital that performs more effectively, as a whole, in the event of an emergency or disaster;
- examine the activities carried out in the different departments of a hospital and the interactions between them;
- define medical service procedures applicable in an emergency situation;
- define measures to help improve the functionality of the services provided by the facility and their interaction in the event of an emergency;
- optimize the distribution/assignment of medical staff and establish an auxiliary organizational scheme applicable in emergency situations;
- demand that public utilities assess the vulnerability of external lifelines as part of an integrated local or national vulnerability reduction programme; local authorities (institutions) must also make sure that the various actors play the roles expected of them in an emergency in order to guarantee the supply of basic public services to the hospital;
- continually maintain the quality of equipment, lifelines and backup systems; and
- plan in advance, with the support of public service providers such as firefighters, paramedics, civil defence officials and transit authorities, in order to establish cooperation and coordination agreements.

Most hospital authorities have established formal disaster mitigation plans, but most of these plans fail to provide administrative and organizational alternatives in the event of severe damage to the facilities. The best way to reduce the administrative/organizational vulnerability of a health facility is by preparing a quality disaster response plan. This will not be only a formal document but a basis for continually improving procedures and practices, enabling a health facility to function optimally under both normal and emergency conditions. A good and functional response plan is accompanied by education and training of personnel and regular drills, thus providing the preconditions for a successful response in an emergency situation.

# 5. SUMMARY

Health facilities are essential for dealing with the consequences of earthquakes, but they are also highly vulnerable. Other buildings and installations of similar size and construction may exist, but they are not as complex from the functional, technological and administrative points of view. Several factors make health facilities especially vulnerable: complexity; occupancy; critical supplies; basic facilities (infrastructure); heavy objects; hazardous materials; and external dependence (security services and community aid).

Given the importance of an efficient response to emergencies and the need for a functional health care infrastructure in the aftermath of a disaster, hospital administrators must consider all aspects of facility vulnerability. A reliable and comprehensive hospital assessment can be carried out only by taking into account all three main categories of vulnerability in the following order: (*a*) structural; (*b*) nonstructural; and (*c*) administrative/organizational.

It is the duty of the authorities to assess a hospital's vulnerability to the consequences of an earthquake and to obtain estimates of existing risk levels in order to ensure a proper response to emergency needs. Most hospital authorities have established disaster mitigation and response plans. It is necessary to plan in advance, with the support of public service providers such as firefighters, civil defence officials and transport authorities in order to establish cooperation and coordination agreements. All of these inter-institutional mechanisms must be taken into account in a hospitals disaster mitigation and response plan on the basis of the vulnerability of its structure, its equipment and its administration and organization.

Structural vulnerability is related to the susceptibility to various types of damage of the structural elements that are required to physically support the building. These include foundations, columns, bearing walls, beams, staircases and floors. The level of structural vulnerability is controlled by:

- the level of aseismic protection
- architectural and structural configuration problems
- the quality of materials, workmanship and maintenance.

By their nature, health facilities tend to be large and complex, which often causes their configuration to be quite complex as well. Configuration does not refer here simply to the spatial arrangement of the buildings and their components, but to their type, layout, fragmentation, strength and geometry, from which certain problems of structural response to earthquakes are derived. One of the greatest causes of damage to buildings has been the use of improper architectural-structural configurations.

The methods for structural vulnerability assessment can be classified as qualitative and quantitative. Qualitative methods are generally used to evaluate a large sample of buildings or to corroborate the level of safety in a given structure. Quantitative methods are utilized when the importance of the building merits it, or rather when qualitative methods have not been able to assess the safety of the building.

Score assignment methods are the best of the qualitative methods for identifying seismically hazardous buildings by exposing structural deficiencies.

Assessing the condition of an existing building may raise serious doubts about its ability to withstand seismic events, which can lead to the need for retrofitting or rehabilitating the building totally or partially in order to reduce its vulnerability before an event occurs. This is mandatory for essential buildings that respond to the emergencies derived from earthquakes. The execution of proper retrofitting measures should consider physical and functional aspects, structural safety, construction techniques and costs.

Nonstructural vulnerability of health facilities relates to three categories of nonstructural element: architectural elements, installations, and equipment (medical and other) and furnishings.

Ground shaking during an earthquake has three primary effects that cause damage to nonstructural elements in buildings: (*a*) inertial or shaking effects on the nonstructural elements themselves; (*b*) distortions imposed on nonstructural components when the building structure sways back and forth; and (*c*) separation or pounding at the interface between adjacent structures.

The most commonly used nonstructural vulnerability assessment procedures are those based on rapid visual screening, and consider three risk levels for classifying the hazards posed by the failure of nonstructural elements: (1) risk of loss of life; (2) risk of loss of equipment and property; and (3) risk of functional loss.

Once a nonstructural element has been identified as a potential threat and its priority established in terms of loss of life, property and/or function, the appropriate measures must be adopted to reduce or eliminate the hazard. The following 12 mitigation measures have been found effective in many cases: removal, relocation, restricted mobility for certain objects, anchorage, flexible couplings, supports, substitution, modification, isolation, reinforcement, redundancy and rapid response and repair.

The administrative/organizational aspects are one of the most important in ensuring that the disaster prevention and mitigation measures provide undisrupted functioning of the hospital after an earthquake.

Administrative/organizational vulnerability refers primarily to the distribution of space, and the relationships between these spaces and the health care services provided in the hospital. It also refers to the physical and functional relationships between the different areas, and to administrative processes such as hiring, supply procurement and maintenance routines.

Appropriate zoning and relationships between the different areas of a facility can ensure adequate functioning, not only under normal conditions but also in the case of an emergency or disaster. The arrangement and relationship between outpatient consultation areas, areas surrounding the structure and emergency services, and the creation of a specially protected area for general support services, can ensure appropriate medical treatment and avoid the functional collapse that can occur even if the building has not suffered severe damage.

The systematic organization and easy mobilization of staff, equipment and supplies in a safe environment are crucial if disaster response is to be prompt and effective. Buildings, technology and processes are both interdependent and critical. Deficiencies in any of the functional aspects of a hospital can plunge the institution into a crisis.

A new health facility integrated seismic vulnerability evaluation (HVE) method has recently been developed. The method is designed to be suitable for hospital administrators in performing a preliminary (qualitative/quantitative) vulnerability assessment, identifying possible weak elements in the facility and main areas of vulnerability, and in determining priorities for necessary further "in-depth" investigations.

The main characteristics of the HVE method are that:

- it is suitable for use by hospital administrators with non-engineering profiles;
- it is a hybrid, mainly qualitative method using mainly rapid visual screening combined with the screener's judgement;
- it combines separate evaluation methods for the three main vulnerability categories;
- the evaluation process depends on the seismicity level; and
- it takes account of features distinctive of Europe, such as the predominant building typology used for health facilities, and relies on existing vulnerability assessment methods and the European Macroseismic Scale (EMS-98) for determining possible seismic demand.

The rapid visual screening is based on a "sidewalk survey" of a building, using several data collection forms filled out by screeners. The collected data are processed and corresponding vulnerability indices, risk ratings or screener judgements are calculated or assigned in order to evaluate the facility according to structural, nonstructural and administrative/organizational vulnerability or performance.

The following data collection/evaluation forms are incorporated in the HVE method:

- HVE-001: general vulnerability evaluation;
- HSVE-001 and HSVE-002: structural vulnerability evaluation;
- HNVE-001/1, HNVE-001/2 and HNVE-001/3: nonstructural vulnerability evaluation; and
- HOVE-001/1 and HOVE-001/2: administrative/organizational vulnerability evaluation.

Successful completion of the vulnerability evaluation requires appropriate cost estimation and budget development for all its phases: pre-field, field screening and post-field.

Pre-field planning should include the following activities:

- selection and review of the data collection and evaluation forms
- determination of the seismicity of the site
- information on local ground conditions
- review of the design and construction documents (if in existence)
- information on the level of seismic preparedness
- the qualifications of and training for screeners.

Many of the decisions to be made will depend on budget constraints. Although the rapid visual screening procedure is designed so that field screening of each building should take no more than 15–30 minutes, funds should also be allocated for pre-field data collection. This can be extremely useful in reducing the total field time and can increase the reliability of data collected in the field.

A training programme for screeners will be required to ensure a consistently high data quality and uniformity of decisions. It should include discussion on all procedural details and their implementation, with particular emphasis on: identifying lateral-force-resistant systems and how they behave when subjected to seismic loads; how to use the data collection form and how to calculate/evaluate the level of a certain vulnerability category; what to look for in the field; and how to account for uncertainty. In conjunction with a professional engineer experienced in seismic design, screeners should simultaneously consider and score buildings of several different types and compare results. This will serve as a "calibration" for the screeners. This process can easily be accomplished in a classroom setting with photographs of actual buildings as examples. Prospective screeners review the photographs and perform the rapid visual screening procedure as though they were in the field. On completion, the class discusses the results and students can compare how they did in relation to the rest of the class.

Other factors that should also be considered in cost estimation include the development and administration of a record-keeping system for the screening process; data processing and interpretation; and overall management of rapid visual screening (estimated at 10% of the total cost).

In addition to the main purpose, the method itself or some of its parts can also be used for:

- developing inventories of buildings for regional earthquake damage and loss impact assessment;
- developing inventories of health facilities for use in planning post-earthquake response activities;
- supporting building safety evaluation efforts and ranking health care system rehabilitation needs;
- providing elements for community earthquake preparedness; and
- developing building-specific seismic vulnerability information for other needs such as insurance rating.

# REFERENCES


1. *Principles of disaster mitigation in health facilities*. Washington, DC, Pan American Health Organization, 2000 (http://www.paho.org/English/dd/ped/fundaeng.htm, accessed 20 November 2005).
2. Bertero VV. Performance-based seismic engineering: a critical review of proposed guidelines. In: Fajfar P, Krawinkler H, eds. *Proceedings of the International Workshop on Seismic Design Methodologies for the Next Generation of Codes, Bled, Slovenia, June 1997*. Rotterdam, A.A. Balkema, 1997.
3. Lang K. *Seismic vulnerability of existing buildings* [thesis]. Zurich, Institute of Structural Engineering, Swiss Federal Institute of Technology, 2002.
4. Milutinovic ZV, Trendafiloski GS. *Workpackage 4 – vulnerability assessment of current buildings*. RISK-UE Report, September 2003 (http://www.risk-ue.net/update1/PPWP04.htm, accessed 20 November 2005).
5. Trendafiloski GS. [*GIS-oriented method for development of probabilistic earthquake scenarios* [thesis]]. Skopje, Institute of Earthquake Engineering and Engineering Seismology, 2003 (in Macedonian).
6. *FEMA 154. Rapid visual screening of buildings for potential seismic hazards: a handbook*, 2nd ed. Washington, DC, Federal Emergency Management Agency, 2002.
7. *FEMA 155. Rapid visual screening of buildings for potential seismic hazards: supporting documentation*, 2nd ed. Washington, DC, Federal Emergency Management Agency, 2002.
8. *FEMA 74. Reducing the risks of nonstructural earthquake damage: a practical guide*, 3rd ed. Washington, DC, Federal Emergency Management Agency, 1994 (http://www.fema.gov/hazards/earthquakes/nehrp/fema-74.shtm, accessed 18 November 2005).
9. *Real Property Solutions. Guideline on seismic evaluation and upgrading of non-structural building components*. Ottawa, Public Works and Government Services Canada, 1995.
10. Grünthal G, ed. *European macroseismic scale 1998*. Luxembourg, Council of Europe, 1998 (Cahiers du Centre Européen de Géodynamique et de Séismologie, Vol. 21).
11. *FEMA 150. Seismic considerations: health care facilities*. Washington, DC, Federal Emergency Management Agency, 1990.
12. Lungu D et al. *Workpackage 1 – European distinctive features, inventory database and typology*. RISK-UE WP1 Report, December 2001 (http://www.risk-ue.net/update1/PPWP01.htm, accessed 18 November 2005).
13. *Eurocode 8. Design provisions for earthquake resistance of structures. Part 1.1 General rules – seismic actions and general requirements for structures*. London, British Standards Institution, 1996 (DD ENV 1998-1-1: 1996).
14. Lagomarsino S, Giovinazzi S. *A macroseismic method for the vulnerability assessment of buildings*. [Paper presented at the] 13th World Congress on Earthquake Engineering, Vancouver, 1–6 August 2004 (Paper 896).
15. Milutinovic Z, Olumceva T, Trendafiloski G. *Earthquake related emergency capability of large hospital campus in Republic of Macedonia*. Copenhagen, WHO Regional Office for Europe, 1998 (Report IZIIS 98-43/1).

# FURTHER READING

*HAZUS99 SR2. Earthquake Loss Estimation Methodology. Advanced engineering building module*. Washington, DC, Federal Emergency Management Agency, 1999.

*Kobe report of session 4.2, Thematic cluster 4. Vulnerability reduction of health facilities*. World Conference on Disaster Reduction, 18–22 January 2005, Kobe, Japan (http://www.unisdr.org/wcdr/thematic-sessions/thematic-reports/report-session-4-2.pdf, accessed 18 November 2005).

Krauskopf RB, Saavedra RR. *Guidelines for vulnerability reduction in the design of new health facilities*. Washington, DC, Pan American Health organization/World Bank, 2004.

Lee GC et al., eds. Proceedings of the MCEER Workshop for Seismic Hazard Mitigation of Health Care Facilities, New York, NY, 27–28 October 1978. Buffalo, NY, Multidisciplinary Center for Earthquake Engineering Research, 2000 (http://mceer.buffalo.edu/publications/workshop/00-0002/default.asp, accessed 18 November 2005).

Masri S et al. *The FEMA-USC hospital project. Nonstructural mitigation in hospitals*. [Paper presented at the] 13th World Congress on Earthquake Engineering, Vancouver, 1–6 August 2004 (Paper 2480).

Milutinovic Z, Trendafiloski G, Olumceva T. *Disaster preparedness planning for small and medium size hospitals based on structural, nonstructural and functional vulnerability assessment*. Copenhagen, WHO Regional Office for Europe, 1995 (Report IZIIS 95-68).

*Protecting new health facilities from natural disasters: Guidelines for the promotion of disaster mitigation*. Washington, DC, Pan American Health Organization, 2003 (http://www.paho.org/English/DD/PED/proteccion.htm, accessed 20 November 2005).

Whittaker AS, Soong TT. (2003). An overview of nonstructural components research at three US earthquake engineering research centers. In: *Proceedings of the ATC 29-2 Seminar on Seismic Design, Performance, and Retrofit of Nonstructural Components in Critical Facilities, Newport Beach, CA, October 23–24, 2003*. Redwood City, CA, Applied Technology Council, 2003:271–280 (http://www.atcouncil.org/pdfs/Whittaker.pdf, accessed 20 November 2005).

# Annex 1. Health facility vulnerability evaluation forms

## Form HVE-001. General vulnerability evaluation

| GENERAL DATA |
|---|

| | | | |
|---|---|---|---|
| **Municipality** | | **City** | |
| **Name** | | | |
| **Address** | | | |
| **Facility type** | | | |

| | |
|---|---|
| **Facility ID Number** | |

| | | | |
|---|---|---|---|
| **Site area ($m^2$)** | | **Built area ($m^2$)** | |

| | | | |
|---|---|---|---|
| **Employees** | | **Capacity** | |
| Doctors | | Patients/day | |
| Other medical staff | | No. of beds | |
| Administration | | | |
| Other | | | |

| SEISMIC EXPOSURE AND PREPAREDNESS |
|---|

| | |
|---|---|
| **Maximum observed intensity (EMS-98)** | |
| **Seismic zoning** | |

| | |
|---|---|
| **Earthquake response plans** | YES NO |
| **Emergency supplies** | YES NO |
| **Earthquake response training** | YES NO |
| **Drills** | YES NO |

## HEALTH FACILITY PERFORMANCE

| | | | |
|---|---|---|---|
| **Structural performance** | Good | Average | Poor |
| **Nonstructural performance** | Good | Average | Poor |
| **Administrative/organizational performance** | Good | Average | Poor |

Screeners: ______________________________ Date: ______________

______________________________

______________________________

## Structural vulnerability evaluation

***Form HSVE-001. Masonry buildings***

| *Plan* | **General building data** | |
|---|---|---|
| | Building No. | |
| | Year built | |
| | Building type | |
| | No. of storeys | |
| | Total building area | |
| | Building function | |
| *Elevation* | PHOTOGRAPH | |

| **Occupancy load** | | **Soil category (EC-8)** | | | **Existing damage** | | | |
|---|---|---|---|---|---|---|---|---|
| *Number of occupants* | | **A** *Rock/Hard* | **B** *Medium* | **C** *Soft* | YES | NO | Retrofit | Reconst. |
| 0–10 | 11–100 | | | | | | | |
| 101–1000 | 1000+ | | | | Please specify the year of intervention: | | | |

| Building type | | Vulnerability indices/modifiers | | | |
|---|---|---|---|---|---|
| | | **M1.2** | **M3.1** | **M3.4** | **M5** |
| **Basic vulnerability index** | | **37** | **37** | **31** | **35** |
| Maintenance | Good | –2 | | | |
| | Bad | +2 | | | |
| No. of storeys | 1–2 | –1 | | | |
| | 3–5 | +1 | | | |
| | 6+ | +3 | | | |
| Soft storey | | +2 | | | |
| Plan irregularity | | +2 | | | |
| Vertical irregularity | | +1 | | | |
| Superimposed floors | | +2 | | | |
| Heavy roof | | +2 | | | |
| Retrofitting interventions | | –2 | | | |
| Ground slope | | +1 | | | |
| Soil conditions | A | –2 | | | |
| | B | 0 | | | |
| | C | +2 | | | |
| **TOTAL VULNERABILITY INDEX =** | | **VULNERABILITY LEVEL = Low/Moderate/High** | | | |
| Comments: | | | | Detailed evaluation required<br><br>**YES** **NO** | |

***Form HSVE-002. Reinforced concrete buildings***

| *Plan* | **General building data** | |
|---|---|---|
|  | Building No. | |
| | Year built | |
| | Building type | |
| | No. of storeys | |
| | Total building area | |
| | Building function | |
| *Elevation* | PHOTOGRAPH | |



| **Occupancy load** | | **Soil category (EC-8)** | | | **Existing damage** | | | |
|---|---|---|---|---|---|---|---|---|
| *Number of occupants* | | **A** *Rock/Hard* | **B** *Medium* | **C** *Soft* | YES | NO | Retrofit | Reconst. |
| 0–10 | 11–100 | | | | Please specify the year of intervention: | | | |
| 101–1000 | 1000+ | | | | | | | |

| Building type | | Vulnerability indices/modifiers | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | RC1 | RC2 | RC3.1 | RC3.4 | RC4 | RC5 | RC6 |
| **Basic vulnerability index** | | **20** | **17** | **20** | **26** | **17** | **17** | **25** |
| Period of construction | | Pre-1970 | | 1970–1980 | | | Post-1980 | |
| Code level | | +8 | | 0 | | | –8 | |
| Maintenance | Good | 0 | | 0 | | | 0 | |
| | Bad | +2 | | +1 | | | 0 | |
| No. of storeys | 1–3 | –2 | | –2 | | | –2 | |
| | 4–7 | 0 | | 0 | | | 0 | |
| | 8+ | +4 | | +3 | | | +2 | |
| Plan irregularity | Shape | +2 | | +1 | | | 0 | |
| | Torsion | +1 | | +1 | | | 0 | |
| Vertical irregularity | | +2 | | +1 | | | 0 | |
| Soft storey | | +3 | | +2 | | | +1 | |
| Short columns | | +1 | | +1 | | | 0 | |
| Type of foundation | Beams | –2 | | 0 | | | 0 | |
| | Concrete beams | 0 | | 0 | | | 0 | |
| | Footings | +2 | | 0 | | | 0 | |
| Ground slope | | +1 | | +1 | | | +1 | |
| Soil conditions | A | –1 | | –2 | | | –2 | |
| | B | 0 | | 0 | | | 0 | |
| | C | +2 | | +1 | | | +1 | |
| **TOTAL VULNERABILITY INDEX =** | | **VULNERABILITY LEVEL = Low/Moderate/High** | | | | | | |
| Comments: | | | | | Detailed evaluation required<br>**YES** **NO** | | | |

## Nonstructural vulnerability evaluation

***Form HNVE-001/1. Architectural elements***

Building No. _____

| Nonstructural element | Seismic intensity | Type of risk | | | Priority |
|---|---|---|---|---|---|
| | | LS | PL | LF | |
| Divisions and partitions | Low | L | L | L | |
| | Moderate | M | M | M | |
| | High | H | H | H | |
| Interiors | Low | L | L | L | |
| | Moderate | M | M | L | |
| | High | H | H | L | |
| Ceilings | Low | L | L | L | |
| | Moderate | M | M | M | |
| | High | H | H | H | |
| Lighting | Low | L | L | L | |
| | Moderate | H | L | L | |
| | High | H | M | M | |
| Glass | Low | L | L | L | |
| | Moderate | M | M | L | |
| | High | H | M | M | |

| | | | | | |
|---|---|---|---|---|---|
| | Moderate | M | M | L | |
| | High | H | M | M | |
| Facades, cornices, parapets | Low | L | L | L | |
| | Moderate | M | M | L | |
| | High | H | H | L | |
| Chimneys | Low | L | L | L | |
| | Moderate | M | M | L | |
| | High | H | M | M | |
| **TOTAL PL SCORE** | TPL = [ __ x L (1) + __ x M (2) + __ x H (3)] / NE = __ (   ) | | | | |
| **TOTAL LF SCORE** | TLF = [ __ x L (1) + __ x M (2) + __ x H (3)] / NE = __ (   ) | | | | |

***Notes:***

Seismic intensity (EMS-98): Low = <5; Moderate = 5–8; High = >8

Type of risk: **LS** = Life safety; **PL** = Property loss; **LF** = Loss of function

Risk ratings: **L** = Low; **M** = Moderate; **H** = High

NE = No. of elements

| | **Low** | **Moderate** | **High** |
|---|---|---|---|
| Vulnerability level (TPL) | 1–1.7 | 1.7–2.3 | 2.3–3 |
| Consequences (TLF) | 1–1.7 | 1.7–2.3 | 2.3–3 |

***Form HNVE-001/2.* Equipment and furnishings**

Building No. ____

| **Nonstructural element** | **Seismic intensity** | **Type of risk** | | | **Priority** |
|---|---|---|---|---|---|
| | | **LS** | **PL** | **LF** | |
| Medical equipment | Low | L | M | M | |
| | Moderate | M | H | H | |
| | High | M | H | H | |
| Office equipment | Low | L | L | L | |
| | Moderate | L | L | M | |
| | High | L | M | H | |
| Furnishings | Low | L | L | L | |
| | Moderate | L | M | L | |
| | High | L | M | L | |
| Supplies | Low | L | L | M | |
| | Moderate | L | M | M | |
| | High | M | H | H | |
| Clinical files | Low | L | L | L | |
| | Moderate | M | M | M | |
| | High | M | M | H | |
| Pharmacy shelving | Low | L | L | L | |
| | Moderate | H | M | H | |
| | High | H | H | H | |
| **TOTAL PL SCORE** | TPL = [ __ x L (1) + __ x M (2) + __ x H (3)] / NE = __ ( ) | | | | |
| **TOTAL LF SCORE** | TLF = [ __ x L (1) + __ x M (2) + __ x H (3)] / NE = __ ( ) | | | | |

***Notes:***

Seismic intensity (EMS-98): Low = <5; Moderate = 5–8; High = >8

Type of risk: **LS** = Life safety; **PL** = Property loss; **LF** = Loss of function

Risk ratings: **L** = Low; **M** = Moderate; **H** = High

NE = No. of elements

| | **Low** | **Moderate** | **High** |
|---|---|---|---|
| Vulnerability level (TPL) | 1–1.7 | 1.7–2.3 | 2.3–3 |
| Consequences (TLF) | 1–1.7 | 1.7–2.3 | 2.3–3 |

***Form HNVE-001/3. Basic installations and services***

Building No. ____

| Nonstructural element | Seismic intensity | Type of risk | | | Priority |
|---|---|---|---|---|---|
| | | LS | PL | LF | |
| Medical gases | Low | L | L | L | |
| | Moderate | M | M | M | |
| | High | H | M | H | |
| Industrial fuel | Low | L | L | L | |
| | Moderate | M | H | M | |
| | High | H | H | M | |
| Electricity | Low | L | L | M | |
| | Moderate | L | M | H | |
| | High | L | H | H | |
| Telecommunications | Low | L | L | L | |
| | Moderate | L | M | H | |
| | High | L | M | H | |
| Plumbing system | Low | L | L | L | |
| | Moderate | M | M | M | |
| | High | M | M | H | |
| Integrated heating, ventilation and air conditioning | Low | L | M | L | |
| | Moderate | L | M | L | |
| | High | M | H | M | |
| Fire detection and suppression | Low | L | M | M | |
| | Moderate | L | H | H | |
| | High | M | H | H | |
| Elevators (lifts) | Low | L | L | L | |
| | Moderate | L | M | M | |
| | High | M | M | M | |
| **TOTAL PL SCORE** | TPL = [ __ x L (1) + __ x M (2) + __ x H (3)] / NE = __ ( ) | | | | |
| **TOTAL LF SCORE** | TLF = [ __ x L (1) + __ x M (2) + __ x H (3)] / NE = __ ( ) | | | | |

***Notes:***

Seismic intensity (EMS-98): Low = <5; Moderate = 5–8; High = >8

Type of risk: **LS** = Life safety; **PL** = Property loss; **LF** = Loss of function

Risk ratings: **L** = Low; **M** = Moderate; **H** = High

NE = No. of elements

| | Low | Moderate | High |
|---|---|---|---|
| Vulnerability level (TPL) | 1–1.7 | 1.7–2.3 | 2.3–3 |
| Consequences (TLF) | 1–1.7 | 1.7–2.3 | 2.3–3 |

## Administrative/organizational vulnerability evaluation

***Form HOVE-001/1. Capability assessment***

| Existing | Medical services | Importance | Capability | | | |
|---|---|---|---|---|---|---|
| | | | Assigned personnel | Emergency supplies | Medical equipment | Backup systems |
| ☐ | Trauma and orthopaedics | 5 | | | | |
| ☐ | Intensive care | 5 | | | | |
| ☐ | Emergency care | 5 | | | | |
| ☐ | Diagnostic imaging | 5 | | | | |
| ☐ | Surgery | 5 | | | | |
| ☐ | Blood bank | 5 | | | | |
| ☐ | Paediatrics | 4 | | | | |
| ☐ | Urology | 5 | | | | |
| ☐ | Haemodialysis | 4 | | | | |
| ☐ | Gynaecology and obstetrics | 3 | | | | |
| ☐ | Neonatology | 3 | | | | |
| ☐ | Respiratory medicine | 2 | | | | |
| ☐ | Internal medicine | 3 | | | | |
| ☐ | Infectious diseases | 3 | | | | |
| ☐ | Otorhinolaryngology | 1 | | | | |
| ☐ | Ophthalmology | 2 | | | | |
| ☐ | Oncology | 1 | | | | |
| ☐ | Neurology | 3 | | | | |
| ☐ | Psychiatry | 1 | | | | |
| ☐ | Dermatology | 1 | | | | |
| ☐ | Dental medicine | 1 | | | | |
| ☐ | Physiotherapy and rehabilitation | 1 | | | | |
| ☐ | Recovery (inpatients) | 5 | | | | |
| ☐ | Laboratory | 4 | | | | |
| ☐ | Sterilization | 5 | | | | |
| ☐ | Pharmacy | 5 | | | | |
| ☐ | Nutrition | 5 | | | | |
| ☐ | Administration | 3 | | | | |
| ☐ | Laundry services | 4 | | | | |

**IMPORTANCE**

**5 Indispensable**
**4 Very necessary**
**3 Necessary**
**2 Preferable**
**1 Dispensable**

**CAPABILITY**

1. **Optimal:** Efficient allocation of resources and personnel
2. **Adequate:** Acceptable allocation of resources and personnel; operations can proceed normally
3. **Minimal:** Barely acceptable allocation of resources or personnel; operations can proceed with certain restrictions
4. **Inadequate:** Unacceptable assignment of resources or personnel; severe limits on or impossibility of carrying out the activity in question

**Overall capability rating**

**High** ☐

**Moderate** ☐

**Low** ☐

***Form HOVE-001/2. Spatial distribution of services***

**Medical services interrelationship matrix**

**1** No relationship
**2** Indirect relationship
**3** Direct relationship
**4** Key relationship

| | Administration | Outpatient care | Radiology | Clinical laboratory | Pathological Anatomy | Physiotherapy | Emergency care | Surgery | Obstetrics | Sterilization | Intensive care | Hospital admissions | Staff dressing room | Kitchen | Maintenance | Machine room |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Outpatient care | 3 | | | | | | | | | | | | | | | |
| Radiology | 3 | 4 | | | | | | | | | | | | | | |
| Clinical laboratory | 3 | 4 | 2 | | | | | | | | | | | | | |
| Pathological anatomy | 3 | 2 | 1 | 3 | | | | | | | | | | | | |
| Physiotherapy | 3 | 3 | 4 | 1 | 1 | | | | | | | | | | | |
| Emergency services | 3 | 3 | 4 | 4 | 4 | 1 | | | | | | | | | | |
| Surgery | 3 | 3 | 4 | 4 | 4 | 1 | 4 | | | | | | | | | |
| Obstetrics | 3 | 3 | 4 | 4 | 4 | 1 | 4 | 4 | | | | | | | | |
| Sterilization | 3 | 3 | 2 | 2 | 2 | 1 | 4 | 4 | 4 | | | | | | | |
| Intensive care | 3 | 3 | 4 | 4 | 4 | 1 | 4 | 4 | 4 | 3 | | | | | | |
| Admissions | 3 | 1 | 3 | 3 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | | | | | |
| Staff dressing room | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | | | | |
| Kitchen | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 4 | 3 | 3 | | | |
| Maintenance | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 3 | 3 | | |
| Machine room | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 4 | 4 | |
| Laundry room | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 4 | 3 | 4 | 4 | 4 |

| | |
|---|---|
| **Good** | ☐ |
| **Average** | ☐ |
| **Poor** | ☐ |

## FACILITY EXTERNAL INTERDEPENDENCE (LIFELINES)

| **Access to facility** | **Good** | **Average** | **Poor** |
|---|---|---|---|
| Vehicle | ☐ | ☐ | ☐ |
| Pedestrian | ☐ | ☐ | ☐ |
| Helicopter landing | Surface | ☐ | |
| | Rooftop | ☐ | |

| **Water supply** | **Regular** | **Backup** |
|---|---|---|
| Community utility | ☐ | ☐ |
| On-site well | ☐ | ☐ |
| On-site reservoir | ☐ | ☐ |
| Water treatment installation | ☐ | ☐ |

| **Electrical power** | |
|---|---|
| Community utility | ☐ |
| **Backup system** | |
| Partial load of facility and operation | ☐ |
| Full load of facility and operation | ☐ |

| **Communication** | **Regular** | **Backup** |
|---|---|---|
| Telephone | ☐ | ☐ |
| Radio connection | ☐ | ☐ |
| Internet | ☐ | ☐ |

| **Heating system** | |
|---|---|
| Community utility | ☐ |
| On-site utility | ☐ |

| **Cooling system** | |
|---|---|
| Integrated system (HVAC) | ☐ |
| Dispersed system | ☐ |

| **Overall rating** | **Good** | **Average** | **Poor** |
|---|---|---|---|
| Water supply | ☐ | ☐ | ☐ |
| Electrical power | ☐ | ☐ | ☐ |
| Lifelines maintenance | ☐ | ☐ | ☐ |

# Annex 2. The main building types used for health facilities in Europe

## M1.2 Simple stone masonry buildings

This typology is represented by buildings of 1–2 and rarely 3 storeys, constructed of unreinforced solid unit stone masonry, in which loads are completely or partially carried by walls and partitions. The stones have undergone some dressing prior to use and are arranged in the wall in a manner that improves the strength of the structure. This typology also includes buildings of roughly dressed masonry, as long as the stones are of adequate size and texture; they may sometimes include smaller stones used to increase contact.

The load-carrying walls may be constructed of dry stone masonry, plain stone with low quality mortar or plain stone with good quality mortar and stone masonry with timber belts. Interior partitions are generally of stone, rarely of brick or other masonry (adobe, hollow block masonry, etc.)

Roofs and floors are traditionally wooden. The roof cover is most frequently of clay tiles. Foundations are stone masonry in lime mortar.

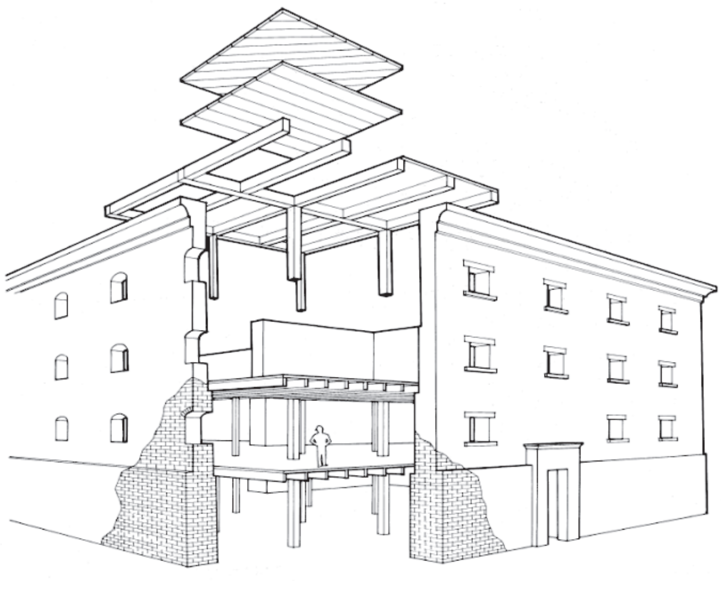
## M3.1 Unreinforced masonry buildings with wooden floors

This building typology is represented by buildings of 1–2 and rarely 3 storeys (Fig. A2.1) with unreinforced plain brick, concrete or hollow block masonry in sludge, lime or cement mortar. The load carrying system is composed of masonry walls. Partitions are of the same materials.

Roofs and floors are traditionally wooden. Foundations are stone masonry in lime or cement mortar.

The vulnerability of this building type is mainly determined by the number, size and position of openings in the walls.

**Fig. A2.1. M3.1 masonry building type**



*Source*: Federal Emergency Management Agency *(6)*.

### M3.4 Unreinforced masonry buildings with reinforced concrete floors

This building typology is represented by buildings of 1–2 and rarely 3 storeys with unreinforced plain brick, concrete or hollow block masonry in sludge, lime or cement mortar. The load carrying system is composed of masonry walls. Partitions are of the same materials.

The roofs are traditionally wooden or rarely reinforced concrete. The floors are reinforced concrete with reinforced concrete belts.

Foundations are of stone masonry in lime or cement mortar or plain or reinforced concrete.

The vulnerability of this building type is mainly determined by the number, size and position of openings in the walls, although its seismic behaviour is much better that that of M3.1 buildings.

### M5 Overall strengthened masonry buildings

This building typology is mainly presented by newly constructed or strengthened brick masonry buildings.

Buildings are not over 3 storeys with superior earthquake damage control features, including exterior walls of (*a*) reinforced solid brick masonry and/or (*b*) reinforced hollow brick masonry or reinforced concrete brick masonry and/or (*c*) reinforced hollow concrete block masonry. Exterior and/or interior bearing walls are strengthened by horizontal reinforced concrete belts at storey levels or by horizontal and vertical reinforced concrete belts connected also at storey levels. Interior partitions or bearing walls may be of any of the aforementioned materials.

Roofs and floors may be of any material: reinforced concrete slabs, reinforced concrete slabs on reinforced concrete beams and/or cast-in-place reinforced concrete slabs on hollow brick units supported by reinforced concrete beams. Any of the aforementioned floor structures or a tiled wooden structure may be used for roofing.

Foundations are of plain concrete, reinforced concrete or stone masonry in lime or cement mortar.

This building typology is considered to be moderately earthquake resistant.

### RC1 Reinforced concrete moment-resistant frame buildings

Reinforced concrete frame buildings are modern earthquake-resistant buildings. They are frequently multistorey structures.

These structures have complete cast-in-place reinforced concrete frames in both directions with all loads (vertical and horizontal) carried by them (Fig. A2.2). Exterior, interior and partition walls may be of solid brick masonry, hollow brick and concrete masonry, light concrete blocks, prefabricated light panels or any non-load-carrying material.

The floors and roof should be of reinforced concrete slabs, reinforced concrete slabs on reinforced concrete beams in one or both directions, reinforced concrete lift slab floors, etc. The foundations are reinforced concrete of different types, depending on the soil conditions.

### RC2 Reinforced concrete shear wall buildings

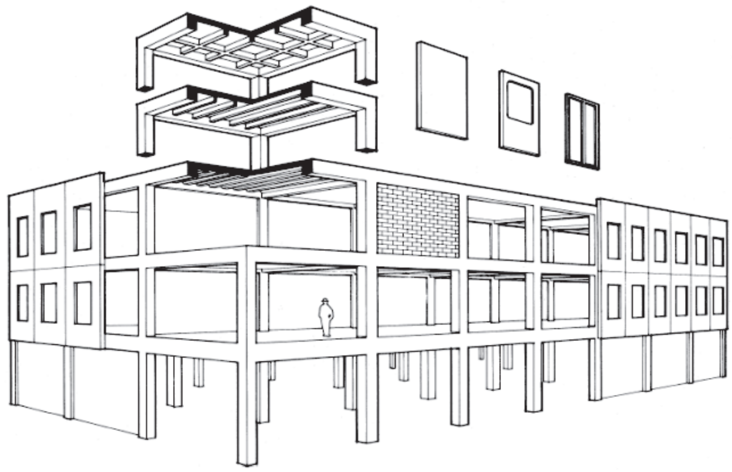
The vertical components of the lateral-force-resisting system type consist of cast-in-place reinforced concrete structural walls in both directions. In older buildings, the walls often have quite extensive cross-sectional areas so that the wall gravity stresses are low and both vertical and horizontal reinforcing is very light. In newer reinforced concrete shear wall buildings, the structural walls, generally properly designed and detailed, are often limited in extent, generating concern about boundary members and shear resistance of the walls (Fig. A2.3).

Exterior, interior and partition walls may be of solid brick masonry, hollow brick and concrete masonry, light concrete blocks, prefabricated light panels or any non-load-carrying material.

The floors and roof should be of reinforced concrete slabs, reinforced concrete slabs on reinforced concrete beams in one or both directions, reinforced concrete lift slab floors, etc.

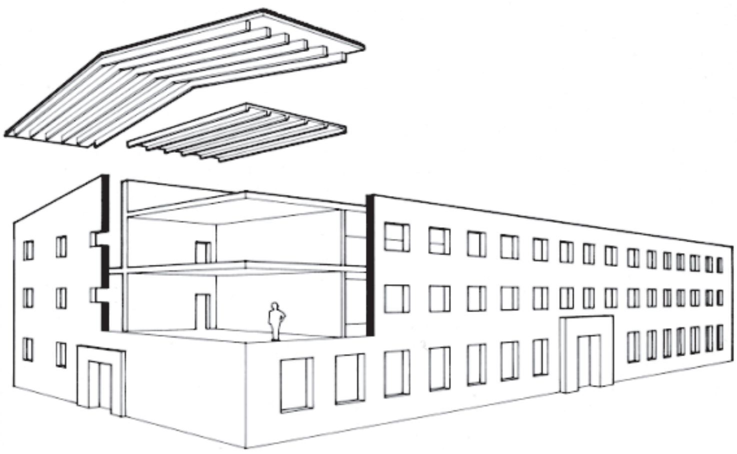
The foundations are reinforced concrete of different types, depending on the soil conditions.

**Fig. A2.2. RC1 building type**



*Source*: Federal Emergency Management Agency *(6)*.

**Fig. A2.3. RC2 building type**



*Source*: Federal Emergency Management Agency *(6)*.

## RC3.1 Buildings with reinforced concrete frames with regularly distributed unreinforced masonry infill walls

This building type is generally without earthquake-resistant design, but has a regular masonry infill that can significantly help its lateral resistance.

Exterior, interior and partition walls may be of solid brick masonry, hollow brick and concrete masonry, light concrete blocks or any non-load-carrying material.

The infill walls are usually offset from the exterior frame members, wrap around them, and show a smooth masonry exterior with no indication of the frame. Solidly infilled masonry panels, when they fully engage the surrounding frame members, may provide adequate stiffness and lateral load resistance to the structure. In these buildings, the fragility of the columns, after cracking of the infill, may limit the semi-ductile behaviour of the system.

### RC3.4 Buildings with irregular reinforced concrete frames

This building type is similar to RC3.1, except that the structural system exhibits a lack of regularity of the concrete frames or of the infill walls.

The concrete frame irregularities and/or the presence of soft/weak storeys (especially the ground floor) produce poor structural behaviour when subjected to lateral loads.

### RC4 Reinforced concrete dual-system buildings

This building type has superior earthquake damage control features. The structural system consists of cast-in-place frames and reinforced concrete bearing walls. Exterior, interior and partition walls may be of solid brick masonry, hollow brick and concrete masonry, light concrete blocks, prefabricated light panels or any non-load-carrying material.

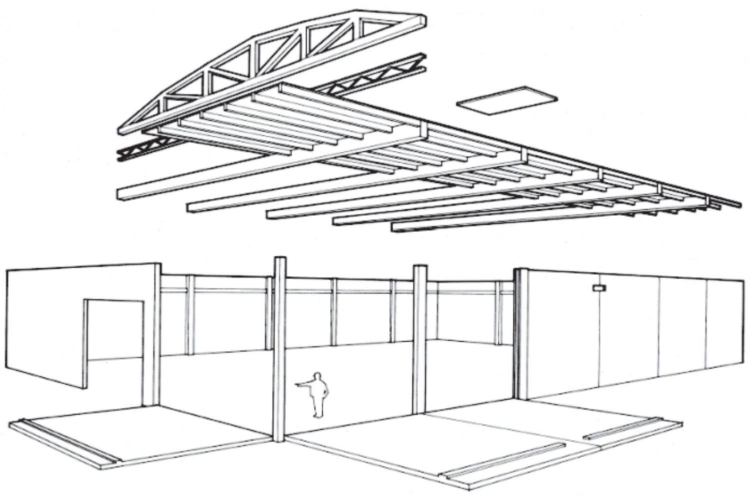
The floors and roof should be of reinforced concrete slabs, reinforced concrete slabs on reinforced concrete beams in one or both directions, reinforced concrete lift slab floors, etc.

The foundations are reinforced concrete of different types, depending on the soil conditions.

### RC5 Buildings of precast concrete tilt-up walls

This building type consists of precast reinforced concrete shear walls connected by precast reinforced concrete slabs (Fig. A2.4). Older buildings often have inadequate connections for anchoring the walls to the slabs and, more generally, the precast panel connections are often brittle. Walls can have numerous openings for doors and windows of such size that the wall looks more like a frame than a shear wall.

**Fig. A2.4. RC5 building type**

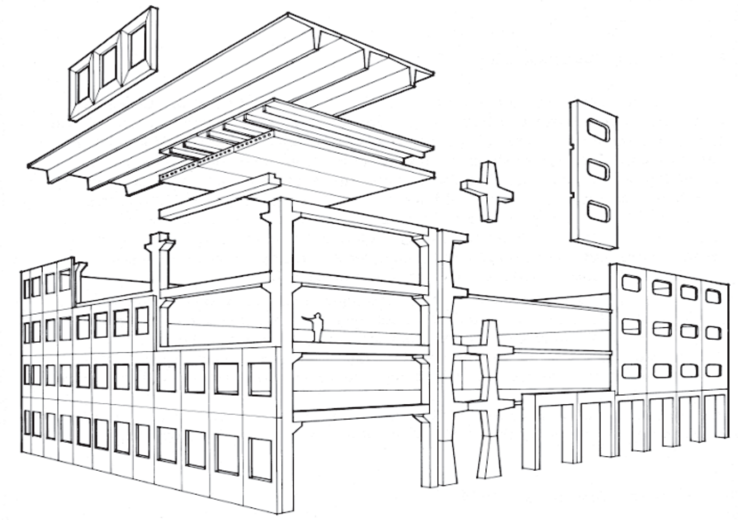


*Source*: Federal Emergency Management Agency *(6)*.

### RC6 Buildings of precast concrete frames with concrete shear walls

This building type consists of reinforced concrete slabs typically composed of precast elements with or without cast-in-place concrete topping slabs (Fig. A2.5). Precast concrete girders and columns support the floor and roof slabs. Closure strips between precast floor elements and beam-column joints are usually cast-in-place concrete. Welded steel inserts are often used to interconnect precast elements. Cast-in-place and even precast reinforced concrete shear walls resist lateral loads. For buildings with precast frames and cast-in-place concrete shear walls to perform well, the details used to connect the structural elements must have sufficient strength and displacement capacity; in some cases, however, the connection details between the precast elements have negligible ductility.

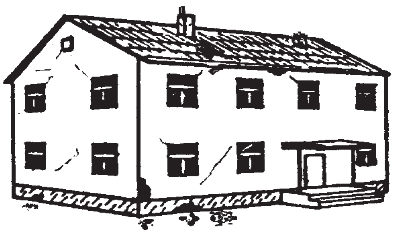
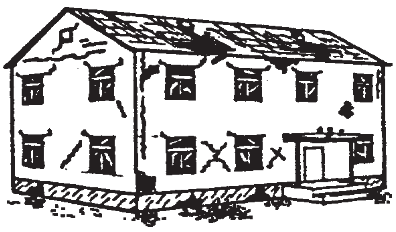
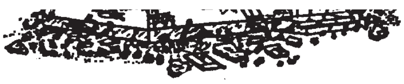
**Fig. A2.5. RC6 building type**



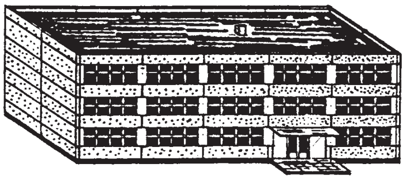
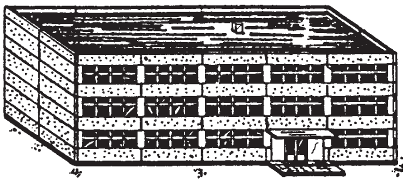
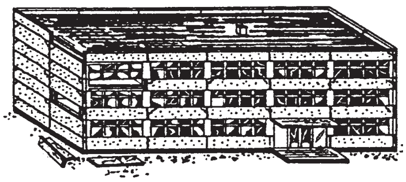
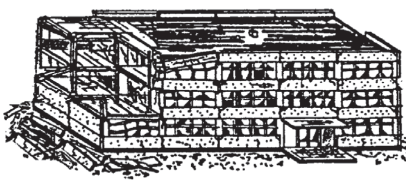
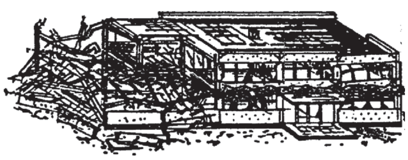
*Source*: Federal Emergency Management Agency *(6)*.

# Annex 3. Grading of seismic damage to buildings according to EMS-98

### A. Classification of damage to masonry buildings

| | |
|---|---|
|  | **Grade 1: negligible to slight damage**<br>*(no structural damage, slight nonstructural damage)*<br>Hairline cracks appear in a very few walls. Only small pieces of plaster fall. Loose stones fall from upper parts of buildings in a very few cases. |
|  | **Grade 2: moderate damage**<br>*(slight structural damage, moderate nonstructural damage)*<br>Cracks appear in many walls. Fairly large pieces of plaster fall. Chimneys partially collapse. |
|  | **Grade 3: substantial to heavy damage**<br>*(moderate structural damage, heavy nonstructural damage)*<br>Large and extensive cracks appear in most walls. Roof tiles detach. Chimneys fracture at roofline. Failure of individual nonstructural elements (partitions, gable walls). |
|  | **Grade 4: very heavy damage**<br>*(heavy structural damage, very heavy nonstructural damage)*<br>Serious failure of walls. Partial structural failure of roofs and floors. |
|  | **Grade 5: destruction**<br>*(very heavy structural damage)*<br>Total or near total collapse. |

## B. Classification of damage to reinforced concrete buildings

| | |
|---|---|
|  | **Grade 1: negligible to slight damage**<br>*(no structural damage, slight nonstructural damage)*<br>Fine cracks appear in plaster over frame members or in walls at the base. Fine cracks appear in partitions and infills. |
|  | **Grade 2: moderate damage**<br>*(slight structural damage, moderate nonstructural damage)*<br>Cracks appear in columns and beams of frames. Cracks appear in partition and infill walls. Brittle cladding and plaster fall. Mortar falls from the joints of wall panels. |
|  | **Grade 3: substantial to heavy damage**<br>*(moderate structural damage, heavy nonstructural damage)*<br>Cracks appear in columns and beam column joints of frames at the base and at joints in coupled walls. Spalling of concrete cover and buckling of reinforced rods occurs. Large cracks appear in partition and infill walls and individual infill panels fail. |
|  | **Grade 4: very heavy damage**<br>*(heavy structural damage, very heavy non-structural damage)*<br>Large cracks appear 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**<br>*(very heavy structural damage)*<br>Collapse of ground floor or parts (e.g. wings) of building. |

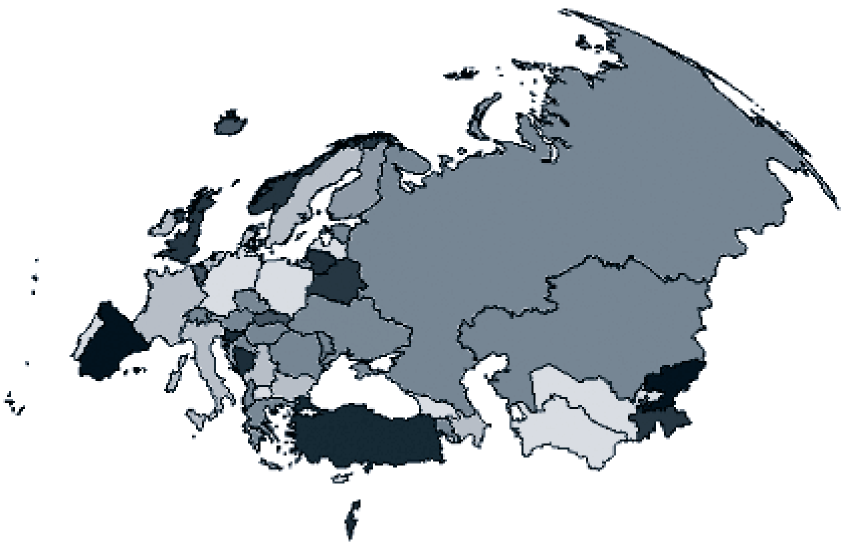
# Annex 4. Seismic exposure estimation

The section on seismic exposure and preparedness in Form HVE-001 (see Annex 1) includes information on seismic zoning in the region where the facility is located. Basically, this is expressed in terms of seismic intensity, peak ground acceleration or spectral values for seismic action with a 475-year return period (10% probability of occurrence in a 50-year period) given in the national aseismic design codes.

Fig. A4.1 presents the status of aseismic design codes in the Member States of the WHO European Region.

For vulnerability evaluation, the countries included in the World List 2004 should use the national seismic zoning given in the code. Countries marked with one or two asterisks are advised to use the former Soviet or Yugoslav codes, respectively. The unmarked countries in the list are advised to use other sources of relevant information, including the GSHAP (http://www.gfz-potsdam.de/pb5/pb53/projects/en/gshap/gshap_e.html) or ESC-SESAME (http://wija.ija.csic.es/gt/earthquakes/) maps shown below.

**Fig. A4.1. Status of aseismic design codes in WHO European Member States**



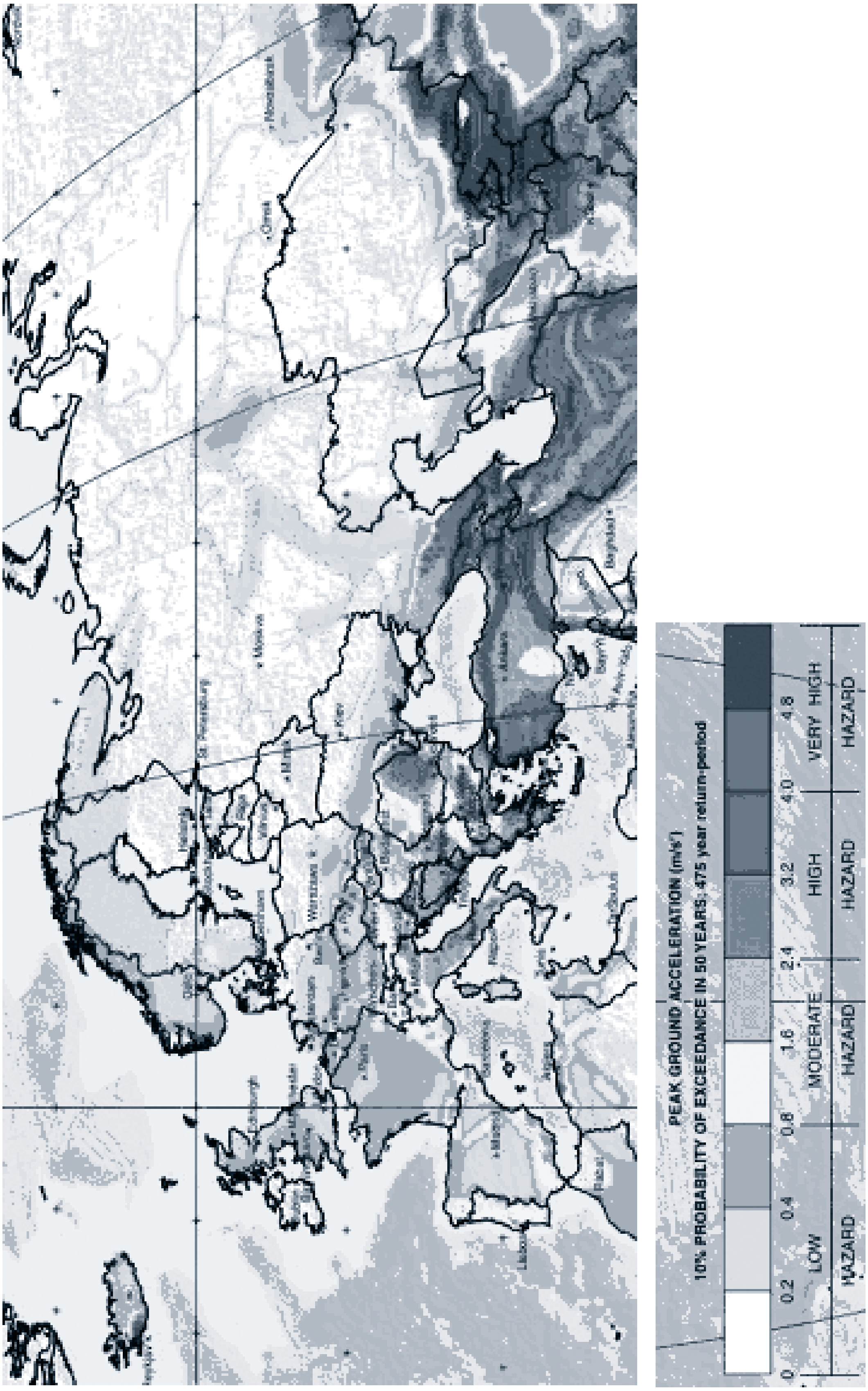
Countries in bold type are included in the latest World List (2004) of regulations for seismic design.

Countries with one asterisk (*) are not included in the latest World List but in the past have used the code of the former USSR.

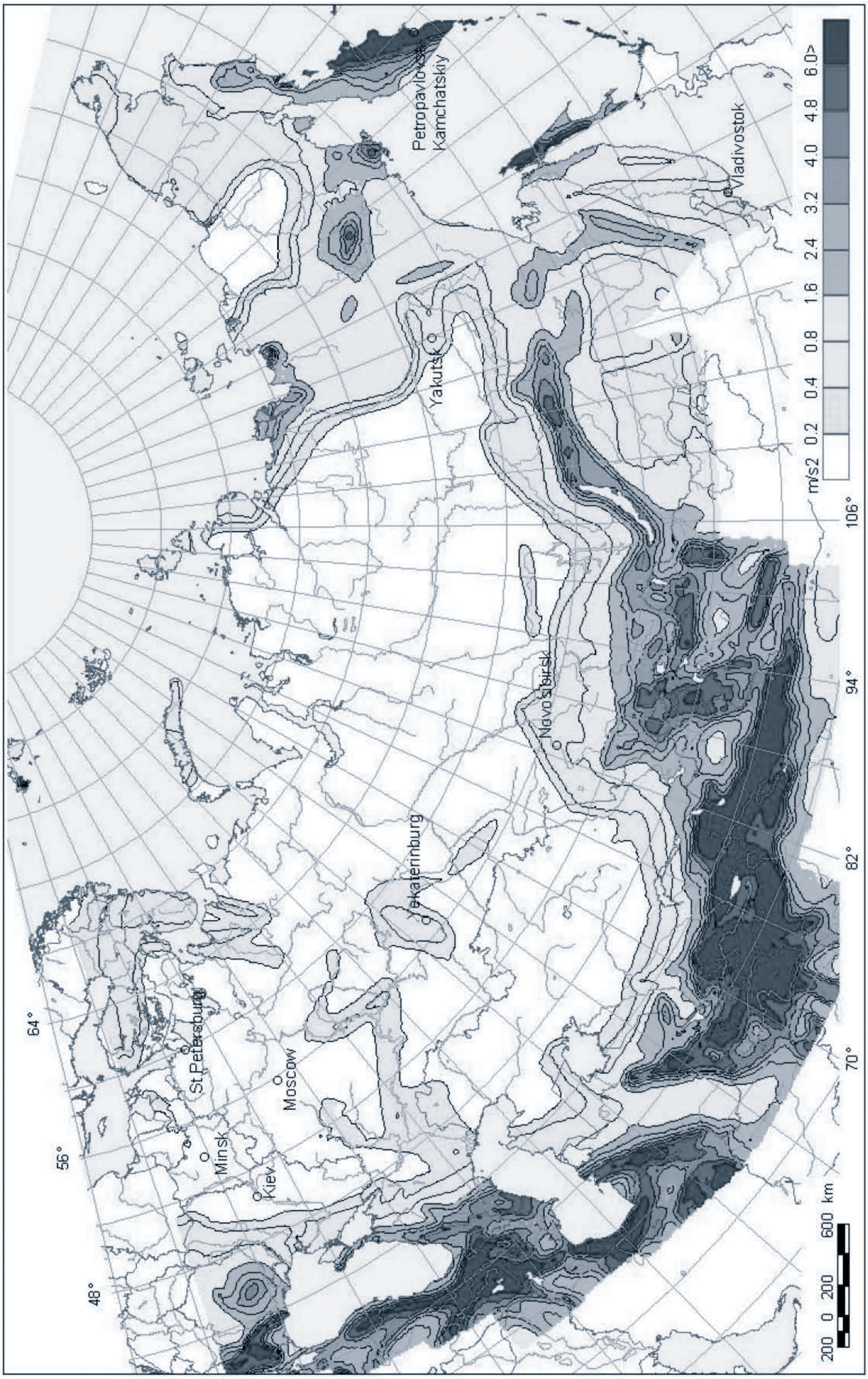
Countries with two asterisks (**) are not included in the latest World List but in the past have used the code of the former Yugoslavia.

1. Albania
2. Andorra
3. Armenia*
4. Austria
5. Azerbaijan*
6. Belarus*
7. Belgium
8. Bosnia and Herzegovina**
9. Bulgaria
10. Croatia
11. Cyprus
12. Czech Republic
13. Denmark
14. Estonia*
15. Finland
16. France
17. Georgia*
18. Germany
19. Greece
20. Hungary
21. Iceland
22. Ireland
23. Israel
24. Italy
25. Kazakhstan*
26. Kyrgyzstan*
27. Latvia*
28. Lithuania*
29. Luxembourg
30. Malta
31. Monaco
32. Netherlands
33. Norway
34. Poland
35. Portugal
36. Republic of Moldova*
37. Romania
38. Russian Federation
39. San Marino
40. Serbia and Montenegro
41. Slovakia
42. Slovenia
43. Spain
44. Sweden
45. Switzerland
46. Tajikistan*
47. The former Yugoslav Republic of Macedonia
48. Turkey
49. Turkmenistan*
50. Ukraine*
51. United Kingdom
52. Uzbekistan*

*The designations employed and the presentation of this material do not imply the expression of any opinion whatsoever on the part of the Secretariat of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.*


PEAK GROUND ACCELERATION (m/s²)
10% PROBABILITY OF EXCEEDANCE IN 50 YEARS; 475 year return-period
0
0.2
0.4
0.8
1.6
2.4
3.2
4.0
4.8
LOW HAZARD
MODERATE HAZARD
HIGH HAZARD
VERY HIGH HAZARD

GSHAP Moscow Regional Center 7 - Chairman V. Ulomov ( UIPE RAS, Russia, ulomov@uipe-ras.scgis.ru ), 1997




**Peak Ground Acceleration (m/s2) Map with 10% Probability of Exceedance in 50 Years for Northern Eurasia**

ESC-SESAME seismic hazard map for WHO European Member States

# Annex 5. Seismic damages to health facilities[1]

| Earthquake | Year | M[2] | General Effects |
|---|---|---|---|
| **Skopje, Former Yugoslavia** | **1963** | **6.1 ($I_o$= IX-X)** | The earthquake devastated the city causing 1,070 deaths and 3,300 heavy injuries. Damage to existing buildings was tremendous. Out of the total building area, 80.7% were destroyed or heavily damaged and about 75.5% of the inhabitants were left homeless. Public buildings, schools, hospitals, industrial buildings etc. suffered very heavy damages. 9 polyclinics and 3 surgeries were destroyed and all other HC facilities were damaged without exception. |
| **Tokachi-oki, Japan** | **1968** | **7.9 (I=X)** | The principal structural systems of the most hospitals have not been damaged, except isolated damages at joints between the structural units. Due to local cracking of slabs, rain leakage was rendered, fixed glasses and glass blocks of windows were remarkably broken, damage of equipment (many of oxygen anesthesia gas, elevators and lifts) was recorded in few cases. Recorded were a few cases of injured patients. The function of all medical facilities without power backup (emergency aggregates) was heavily disturbed. |
| **Banja Luka, Former Yugoslavia** | **1969** | **6.3 (Io=IX)** | The Town Hospital (massive reinforced brick masonry) and associated buildings have severely been damaged. The interior walls were damaged to that extent that the entry in the building was extremely dangerous and prohibited. |
| **San Fernando, USA** | **1971** | **6.5 (Io=XI)** | The earthquake damaged several major hospital complexes, including the Veterans Administration Hospital, the Olive View Hospital (Photo 2.1), the Holy Cross Hospital, and the Pacoima Memorial Lutheran Hospital. At Olive View Hospital, 600 patients had to be evacuated by using two interior stairways because the elevators were inoperative. Flashlights had to be used because the regular and emergency power systems failed. In a severely damaged Veteran's Administration Hospital a total of 47 people have been killed. The only significant search and rescue operation was undertaken at this hospital, and the last survivor was rescued uninjured about 58 hours after the earthquake. The worst damage to medical facilities occurred at the Veterans Administration Hospital in Sylmar where two large buildings collapsed. A number of medical centers also were damaged, and among the most severely affected were the Indian Hills Medical Center, Foothill Medical Building, and the Pacoima Lutheran Professional Building. Nursing homes, such as the Foothill Nursing Home, were also damaged. Of the 58 fatalities caused by building damage, 50 occurred in hospitals. 7 days after the earthquake 1,147 beds were rendered unusable in the hospitals in the area. |
| **Managua, Nicaragua** | **1972** | **6.2 (I=IX)** | In Managua all the hospitals were rendered inoperable. Emergency surgery was performed in the lobby of The Baptist Hospital until the stored water supply failed. |

[1] *This summary was prepared by RDM/IZIIS for the WHO report "Vulnerability of Hospital Environment to Extreme Earthquake Loadings (authors: Zoran MILUTINOVIC, Goran TRENDAFILOSKI, Enrico DAVOLI and Tatjana OLUMCEVA), September 2004, Skopje*

[2] *M - magnitude; $I_o$ - epicentral intensity; I - intensity*

/continue/

| Earthquake | Year | M2 | General Effects |
|---|---|---|---|
| **Montenegro, Former Yugoslavia** | **1979** | **7.2 (Io=IX)** | Two stories reinforced concrete Medical Center in Ulcinj experienced significant structural damage. |
| **Nihonkai-Chubu, Japan** | **1983** | **7.7** | A great extent of structural damage and destruction sustained Namioka Town Hospital. The entire facility was extensively nonstructurally damaged. The greatest structural damage was recorded to third and fourth story of this multi unit five stories building complex. Many glass windows were broken and fallen off. A plastic roof water reservoir was broken at its support. Elevator guide-rails were bent. Slender X-ray apparatus were damaged as well as other medical equipment and medicament stockings. However, no in-patients injury was caused by the earthquake. |
| **Mexico City, Mexico** | **1985** | **8.1 (I=VIII)** | The earthquake killed over 7,000 people. Due to structural collapse (Photo 2.2) of five hospital facilities and major damage of additional 22 hospital buildings a total of 4,397 hospital beds were lost, about one in four of those available in the metropolitan Mexico City area. At least 11 hospitals had to be evacuated. In total 856 people (doctors, nurses, patients, administrative staff and visitors) lost their lives in two collapsed hospitals. Economic losses caused to HC facilities were estimated at over USD 640 million. |
| **Spitak, Armenia** | **1988** | **6.8 ($I_o$=IX-X)** | The town of Spitak (population 25,000) was nearly leveled and more than half of structures in the City of Leninakan (population 250,000) were severely damaged or destroyed. Many modern buildings, including schools and hospitals collapsed, resulting in 25,000 deaths, 15,000 injured and 517,000 people left homeless. A large number of medical facilities were destroyed, killing 80% of medical professionals. |
| **Loma Prieta, USA** | **1989** | **7.1 ($I_o$=X)** | Veteran's Administration hospital complex in Palo Alto area was severely damaged. |
| **Gevgelija, Macedonia** | **1990** | **5.6 (I=VII-VIII)** | The destructive effects of the earthquake on the territory of municipalities of Gevgelija and Valandovo resulted in 2,344 damaged buildings, out of which 201 are public buildings. Eight HC facilities were damaged, among others, the Rehabilitation Center and the Neuropsychiatries Clinic. Also, a brand new medical care unit building was heavily damaged. |
| **Erzincan, Turkey** | **1990** | **6.6 ($I_o$=IX)** | Collapse of three hospitals resulted in 20% of death toll. Most of the care for the injured took place in the State Hospital where a major collapse of five stories Nursing School has occurred, which naturally took the efforts of many of the staff in the first few days. The hospital did not have a mobile unit and many of the operations were done in the open or in tents in extreme sub-zero temperatures. Due to the serious problems with hospital water supply a lot of the work in the first days has to be done without proper sanitary conditions. |

/continue/

| Earthquake | Year | M[2] | General Effects |
|---|---|---|---|
| **Kocaeli, Turkey** | **1999 ($I_o$=X-XI)** | **7.4** | The earthquake killed over 17,500 and injured 44,000 people, destroyed approximately 77,300 houses and businesses and damaged over 245,000. Several hospitals experienced mayor physical damages. At a hospital in Izmit, two buildings and a pedestrian walkway connecting them sustained serious damage. Immediately after the earthquake, medical staff was forced to evacuate the building and move patients outside. A major medical center in Adapazari sustained extensive physical damage to two of its buildings forcing staff members to evacuate patients. Existing patients and new arrivals were assembled outside, sorted and tagged by severity of injury, and transported to other regional hospitals or field hospitals set up by relief organizations. |
| **Duzce, Turkey** | **1999 ($I_o$=IX)** | **7.2** | Towns of Duzce and Bolu were mainly affected. Death toll was reported as 450 with over 3000 injuries. In general, the health care facilities and lifelines within hospitals that were investigated performed quite well. Most of the hospitals had toppled oxygen tanks, as they were not anchored. Other unsecured equipment that fell from the tables were monitors for heart patients. Only one hospital reported an air conditioning problem. A private hospital collapsed in Düzce (Photo 2.6). |
| **El Salvador, Salvador** | **2001 (I=VII-VIII)** | **7.6** | The earthquake caused nationwide disruption of the medical care system (Photo 2.7) at 6 hospitals and 28 health centers in the following districts: La Libertad (1 hospital and 4 health centers), La Paz (1 hospital and 6 health centers), Sononate (1 hospital and 5 health centers), Santa Ana (1 health center), Usultan (2 hospitals and 7 health centers), San Salvador (4 health centers), San Miguel (1 hospital) and San Vincente (1 health center). 39% (1,917 of hospital beds) of the country's total capacity was put out of service.<br>The hospital San Juan de Dios in San Miguel sustained significant nonstructural damages (collapse of ceilings, breakage of glass windows, rupture of water pipelines, fall of lighting fixtures, etc.) and was evacuated except for a few operating rooms that were usable. A field hospital has been set up in the hospital grounds where both children and adult patients were treated.<br>The San Pedro National Hospital in Usultan has been completely evacuated due to slight structural damages (cracks in some columns) and nonstructural damages (collapse of ceilings, vertical cracking of partitions, rupture of water pipelines and disabled elevators). Treatment of patients continued in a field hospital set up near by. In general, patients at damaged hospitals and health centers were forced to evacuate to temporary/or provisional medical care centers.<br>In Nueva San Salvador, San Rafael Hospital sustained serious structural damage to its old building blocks. New blocks of the hospital also sustained damage. Power and water outages disrupted emergency cares at this hospital for a large number of outpatients injured in the earthquake. |

/continue/

| Earthquake | Year | M[2] | General Effects |
| --- | --- | --- | --- |
| **Gujarat, India** | **2001 ($I_o$=IX)** | **7.7** | The worst damage was caused in eastern Kutchh, in the vicinity of the town of Bachau that was almost completely destroyed. Kutchh was cut off from the rest of the country for more than 24 hours. Many multi-storied buildings collapsed, including the housing quarters at the Indian Air Force base and the 8-storey Sahajanand Complex in Bhuj. The worst damage was concentrated in the old city of Bhuj. Jubilee Hospital, the main hospital in the city was leveled and so were many other medical facilities across Kutchh (Photos 2.8-2.10). |
| **Tbilisi, Georgia** | **2002** | **M=4.5 ($I_o$=VI)** | Earthquake killed 7, injured approximately 30 persons, three of them very seriously. 2,500 building were damaged, mostly in the old part of the city. Essential public buildings – educational institutions, hospitals, clinics, kindergartens received considerable material losses. Interruption of the electricity and water supply in some parts of Tbilisi was reported due to damage to supply lines.<br><br>Out of 120 hospital buildings checked in 10 affected regions, 32 (26.7%) hospital buildings reported nonstructural and 38 (31.7%) structural damages, out of which 8 buildings (6.7%) have been severely damaged. Total direct losses have been estimated at 4.0 billion USD. |
| **Thenia, Algeria** | **2003 ($I_o$=IX)** | **6.8** | The earthquake affected highly developed and urbanized northern part of Algeria. Damage was reported in five of the North-Central provinces. Hardest hit were regions of the cities Boumerdes, Zemmouri and Thenia as well as the eastern districts of the capital Algiers. At leas 2,700 deaths and over 11,000 injuries were reported. Earthquake severely damaged about 19,000 houses and left 182,000 homeless. Health services have been severely affected as infrastructure and equipment was damaged or destroyed. In the affected region 158 HC facilities experienced slight to moderate nonstructural and structural damages, 23 sustained heavy structural damage and 10 were severely damaged or collapsed. In Thenia, the city hospital was hard hit by the quake, which left 80%of the hospital wards destroyed or unusable, including the emergency ward and other key wards such as the surgery block, but also the maternity and pediatric wards. Though the small health center of Zemmouri was less physically affected, the number of casualties and wounded at the epicenter of the quake, where 80% of the buildings were destroyed, quickly overwhelmed both the capacity and the medical stocks of the remaining health staff. Hospitals in the capital and hardest-hit cities were finding it almost impossible to cope. In the worst affected province, Boumerdes, bodies were piled up outside hospitals and patients were treated in the open air. |

/continue/

| Earthquake | Year | M[2] | General Effects |
|---|---|---|---|
| **Al Hoceima, Morocco** | **2004** | **6.3 (I=VIII)** | An earthquake with epicenter located in Gibraltar straight affected northeastern Morocco. The earthquake killed more than 600 people in the mountainous Riff region. In the area, a number of villages with mud-brick buildings unable to withstand earthquakes were destroyed. The main city in the region, Al Hoceima (100,000 residents) was not significantly damaged, but medical facilities were overcrowded with injured people form the affected region. Authorities tried to cope with situation by establishing field hospitals and sending injured to medical facilities in Rabat. |

Photographs illustrating earthquake effects on health facilities can be found at various internet sites (professional or amateur) and for further reference some of them are listed bellow:

www.usgs.gov

www.ngdc.noaa.gov

www.paho.org

www.paho.org/English/DD/PED/photogallery-eng.htm

www.divyajivan.org/gujarat_earthquake.htm

202.54.104.236/intranet/eha/Mitigacion/Contenidos/english/nonstructural.htm

202.54.104.236/intranet/eha/Mitigacion/Contenidos/english/structural.htm

More photos are also available via global search engines.

**The WHO Regional Office for Europe**

The World Health Organization (WHO) is a specialized agency of the United Nations created in 1948 with the primary responsibility for international health matters and public health. The WHO Regional Office for Europe is one of six regional offices throughout the world, each with its own programme geared to the particular health conditions of the countries it serves.

**Member States**

Albania
Andorra
Armenia
Austria
Azerbaijan
Belarus
Belgium
Bosnia and Herzegovina
Bulgaria
Croatia
Cyprus
Czech Republic
Denmark
Estonia
Finland
France
Georgia
Germany
Greece
Hungary
Iceland
Ireland
Israel
Italy
Kazakhstan
Kyrgyzstan
Latvia
Lithuania
Luxembourg
Malta
Monaco
Netherlands
Norway
Poland
Portugal
Republic of Moldova
Romania
Russian Federation
San Marino
Serbia and Montenegro
Slovakia
Slovenia
Spain
Sweden
Switzerland
Tajikistan
The former Yugoslav Republic of Macedonia
Turkey
Turkmenistan
Ukraine
United Kingdom
Uzbekistan

Activity number
WHOLIS number
Original: English

**World Health Organization
Regional Office for Europe**

Scherfigsvej 8, DK-2100 Copenhagen Ø, Denmark
Tel.: +45 39 17 17 17. Fax: +45 39 17 18 18. E-mail: postmaster@euro.who.int
Web site: www.euro.who.int