

MITIGATION OF DISASTERS IN HEALTH FACILITIES



GENERAL ISSUES

VOLUME 1

Pan American Health Organization
Regional Office of the
World Health Organization

MITIGATION OF DISASTERS IN HEALTH FACILITIES

**EVALUATION AND REDUCTION OF PHYSICAL
AND FUNCTIONAL VULNERABILITY**

VOLUME I: GENERAL ISSUES



PAN AMERICAN HEALTH ORGANIZATION
Regional Office of the
WORLD HEALTH ORGANIZATION



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On the cover: The earthquake that ravaged Mexico City on September 19, 1985, was the strongest one recorded in Latin America in the last hundred years. It killed or injured thousands of people and caused severe structural damage. The institutions of the health sector were also very badly hit, including the General Hospital of the National Medical Center of the Mexican Social Security Institute, shown in the photo.

Photography: Julio Vizcarra/PAHO.

PREFACE

The series of documents entitled *Mitigation of Disasters in Health Facilities: Evaluation and Reduction of Physical and Functional Vulnerability* has been prepared by the Pan American Health Organization for national, provincial, or municipal authorities (Volume I: General Issues); owners of buildings, administrators, staff members, and other personnel connected with health installations (Volume II: Administrative Issues); designers, architects, builders, and educators (Volume III: Architectural Issues); and for design engineers, planners, builders, and educators (Volume IV: Engineering Issues).

The purpose of the series is to inform the people involved in the planning, operation, management, and design of health services concerning possible effects of natural disasters on health installations. The idea is to provide a useful tool that makes it possible to incorporate risk mitigation procedures both in the inspection of existing installations and in the design and construction of new buildings and services.

Each volume in the series deals with specific subjects related to the potential problems that can arise when a disaster occurs and, also, discusses the measures that should be taken to mitigate risk, placing special emphasis on the necessary requirements to ensure that installations can continue functioning during and immediately after a sudden impact disaster.

Although health installations can be affected by a broad spectrum of natural phenomena such as earthquakes, hurricanes, landslides, volcanic eruptions, floods, etc., as well as by man-made disasters, such as fires, explosions, gas leaks, and others, the series emphasizes the seismic problem, given that it is the natural phenomenon that has most affected health installations in the world and since, if its direct and indirect effects can be reduced, the risk posed by other phenomena, whose impact is normally less than that which earthquakes can cause, will also be lowered.

The manuals for architects and engineers address professionals familiar with architectural design and with structural analysis and design, respectively. Their approach is to raise concern about traditional techniques and to contribute proposals that are not usually to be found in the standard, specialized reference books.

The Pan American Health Organization/World Health Organization has chosen to promote the preparation and publication of this series as a contribution to the goals of the International Decade for Natural Disaster Reduction (IDNDR).

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EXECUTIVE SUMMARY

Hospitals and health installations in general are exposed elements that can suffer serious damage as a consequence of the occurrence of strong earthquakes. In other words the risk to health installations can be very high, which is why it is necessary to construct any new building in such a way that it is capable of resisting the kind of natural hazards that could occur in its area. It is also necessary to evaluate the vulnerability of existing buildings, in order to identify their weaknesses and to design and carry out the alterations or retrofittings that may be necessary.

In the last 20 years more than 100 hospital facilities, serving an estimated population of between 10 and 12 million people in 9 countries of the Americas, have been affected by earthquakes. Nearly one fifth of those installations collapsed or had to be demolished as a consequence of the damage suffered during disasters. This meant a great toll in human lives and the loss of more than 10,000 hospital beds. At current costs, the replacement value of those beds amounts to more than US\$700 million. Such statistics underscore the need to review the design and criteria for the construction of hospital installations in earthquake-prone areas.

Hospitals require special consideration with regard to the mitigation of risks due to their complexity and occupancy characteristics and to their role during disaster situations, especially in the diagnosis and treatment of the injured and of outbreaks of disease. Hospitals may at any one moment find themselves full of resident patients, transitory patients, staff members, employees and visitors. In the event of disaster, a hospital must continue with the treatment of resident patients and serve the people injured in the disaster. To do this the personnel must know how to respond. The building and its equipment must also remain serviceable.

Most hospital authorities recognize these facts, and for that reason have prepared formal plans for the mitigation of disasters. However, all these plans suffer from the lack of organizational alternatives in the event of severe damage to, or paralysis of, the installations. Little attention has been paid to this, which is worrisome since in many places only one hospital provides medical care, and damage to such a hospital could cause an enormous crisis.

Good systems for organizing and mobilizing personnel, equipment and supplies within a safe environment are fundamental for an effective response to the disaster. This need for systematic arrangements underscores the critical nature and interdependence of

processes, buildings and equipment. Deficiencies in any of these elements of the functional system of a hospital could induce a crisis in the institution.

Moreover, due to the importance and high cost of hospital installations, severe damage to them will not only affect the productive capacity of a country but also public finance due to the cost of rehabilitation and reconstruction.

A hospital building is composed of five basic areas, each of which has very specific functions, but which in turn must interact with other areas in ways that are vital if a hospital is to operate properly. The relations between such areas or sectors—Administration, Ambulatory Care Units, General Services, Outpatient Consultation and Emergency Services, and Inpatient Care Units—can be critical if the original design failed to consider their function and distribution in the case of a sudden influx of patients. A hospital can suffer a "functional collapse" as a result of this situation, which is recognized only at the time an emergency occurs. In addition to the above-mentioned areas, it is important to have an external services area, which plays a particularly important role in dealing with disasters.

A building can remain standing after a disaster but still be unserviceable due to non-structural damage. The cost of the non-structural elements in most buildings is considerably higher than that of the structural elements. This is especially true of hospitals where 85% to 90% of the value of the installation is not in the support columns, floors and beams, but in the architectural design, mechanical and electric systems and in the equipment contained in the building. A relatively minor seismic movement may cause more non-structural damage than damage to structural components. As a result, the most vital aspects of a hospital, those that are most directly related to its purpose and function, are those most easily affected or destroyed by earthquakes. Conversely, it is easier and less expensive to adapt them and prevent them from being damaged or destroyed.

Many of the problems mentioned previously stem from deficiencies in the structural and non-structural safety of the building. The structural component should be considered during the design and construction stage, in the case of a new building, or during repair, remodeling or maintenance, in the case of an existing building. A good structural design is crucial if the building is to withstand a severe earthquake. The building may be damaged, but it is unlikely to collapse. If a hospital collapses even partially, it will be a liability for the community after the disaster and not the asset that it should be.

Unfortunately, in many countries of the Region of the Americas seismic-resistant construction standards have not been effectively applied and in others such standards have not taken into account distinctive specifications for the structures of hospital buildings. Thus, it is hardly surprising that every time that an earthquake occurs in the region the buildings hardest hit are precisely the hospitals, which should be the last to be affected. In other words, the structural vulnerability of hospitals is high, a situation that should be corrected totally or partially if enormous economic and social losses are to be avoided, especially in developing countries.

A vulnerability analysis could begin with a visual inspection of the facilities and with the preparation of a preliminary evaluation. Such an inspection makes it possible to

identify areas that require attention. The report can be discussed with the consultants and the authorities in charge of the facility with a view to defining priorities and timetables for the work to be carried out. Once the retrofitting program has been designed, other reviews and studies should be carried out in specific areas identified as being in need of modification.

Mitigation of the impact of disasters by the adoption of preventive measures is a highly cost-effective activity in areas where disasters are frequent. For every dollar well spent on mitigation before a disaster occurs, much more will be saved in terms of losses prevented. Mitigation is not, in fact, a cost. In the long run it pays for itself. And it does so in real money, and in lives saved.

It follows from the above that functional, structural and non-structural interventions should be based on a very detailed work plan that includes keeping services going at each stage of the process. In the same way there must be coordination between administrative personnel, the medical staff, and the maintenance department of the hospital.

It is not possible to know the cost of reducing the vulnerability of a hospital unless there is a detailed design of the solution and of its implications. However, this does not preclude drawing up a plan in advance with enough precision to ensure that it will only require minimal adjustments as the work proceeds. Usually retrofitting costs are relatively high if they are carried out all at once. However, if the work is carried out by stages, it makes it possible for funds to be assigned more gradually and more in line with a hospital's maintenance budget.

All cases have so far demonstrated the high economic and social returns of improving the structural and non-structural behavior of vulnerable hospital buildings. The cost of retrofitting, although it may sometimes seem to be high, will always be insignificant compared to the services budget or to the cost of repairs or physical replacement. Some good figurative questions to ask in any given case might be, for example: how many scanners could be bought for an amount equivalent to the cost of a retrofitting? And how many scanners does the hospital have? The replies could yield surprising results, without taking into account all the other elements, equipment and goods that the building normally contains, not to mention the human lives involved directly or indirectly and, in general, the social cost of a loss of hospital services.

Consideration of risk in designing hospitals is a responsibility shared by the architect and the engineer. In particular, it should be emphasized that it is shared with regard to the physical relationships between architectural forms and resistant structural systems, and it would be ideal if every designer working in disaster-prone areas understood those relationships. Unfortunately, international educational methods and practice have tended to reduce incentives for promoting this broad approach in the designer's way of thinking since training for new architects is separate from that given to new engineers and, in many cases, they remain separate in practice. As it happens, some architects, by intuition or because of their intellectual background, have an excellent sense of structure, but there are very few of them, and this understanding on their part tends to occur despite their education and practice, rather than as a result.

The loss of life and property caused by earthquakes can be avoided by applying existing technologies and without going to enormous expense. The only thing that is required is the will to do it. Since around two generations are required before the current inventory of buildings in most communities gets replaced, as much attention must be paid to the structural improvement of existing buildings as to the design and construction of new buildings. At this time there exist very few technical limitations to designing and constructing buildings that will resist hurricanes, earthquakes, or other natural hazards. It is possible to minimize risks and damage if preventive measures are incorporated into the design, construction and maintenance of new health installations.

By way of conclusion, the following, briefly summarized, recommendations emerge from this study:

- In all facilities where health services operate, vulnerability and risk analysis of the buildings and their essential hospital equipment should be carried out.
- The procedures governing the purchase of hospital equipment should include a requirement that it meet risk reduction specifications.
- Hospital disaster preparedness plans should be revised with a view to including vulnerability analysis procedures and modifications designed to improve existing installations.
- Construction codes should be compulsory in the design and construction of health sector buildings.
- The administrators, builders and maintenance staff in the health services should have a basic knowledge of the architectural and engineering requirements that their installations should meet in order to be able to withstand the impact of possible natural disasters.
- Hospitals should keep in a safe place information and updated diagrams illustrating the architectural and engineering features of their buildings and technological systems.

INTRODUCTION

The planning, design, and construction of hospitals in areas prone to natural disasters poses numerous challenges for the different professionals involved. Such buildings are important to life under normal circumstances and even more so in the event of having to look after the victims of a disaster. Given the importance of hospitals for the recovery of a community hit by a disaster, for example a strong earthquake, great care has to be taken with the way they are designed. Numerous aspects have to be considered, from the way they are planned to deal with disasters, up to the installation of equipment and various non-structural elements, in addition to the requirements of architectural design, and structural resistance and safety.

Numerous hospitals have in fact suffered serious damage or even functional or structural collapse as a consequence of disasters, particularly following strong earthquakes, depriving their respective communities of adequate care for the victims.

Hence the need to review existing standards for the design and construction of hospitals, orienting them towards the mitigation of disasters, and suggesting a series of possibilities that encourage changes in hospital infrastructure, from conception up to the actual construction and operation of the building.

This document aims to present a series of reflections on the criteria governing design and construction of health infrastructure and puts forward recommendations about ways to mitigate risk to the population and to the investment made in construction of health infrastructure.

Chapter 1 of this manual examines briefly the concepts relating to the characteristics of disasters and in particular seismic hazards and risks. Chapter 2 discusses cases of hospitals in the Americas hit by disasters. It describes some cases that have occurred, the type of damage done, and in general the losses that have been caused by earthquakes in hospitals in recent years. Chapter 3 deals with the importance and function of hospitals in situations of disaster, and with the social and economic costs of a loss of this vital service.

Chapter 4 looks at the various aspects that make hospital buildings vulnerable. It deals with functional vulnerability that can lead to the collapse of hospital services after a disaster, and the potential harm to installations, equipment and non-structural elements.

It also discusses structural vulnerability, which can cost the lives of the occupants of the installation and lead to the total loss of everything inside the building.

Finally, Chapter 5 points out the importance of reducing existing vulnerability and discusses how to do so depending on whether the vulnerability is functional, non-structural, or structural. It comments on the cost-benefit ratio of modifications of existing installations and indicates the importance of taking such recommendations into account in the design of new hospital buildings.

This document is the result of adapting and generalizing from the subjects dealt with in the modules for health administrators, architects and engineers. It aims to be sufficiently simple and complete so that any health professional will be able to grasp the problems of hospital vulnerability to natural disaster hazards and the way in which it can be reduced. Given that this document is not intended to be a manual for the evaluation and mitigation of risks, the reader who would like more information on the subjects dealt with is recommended to refer to the other documents in this series prepared for each of the professional disciplines involved.

CHAPTER 1

CHARACTERISTICS OF DISASTERS

TYPES OF DISASTER

A disaster can be defined as an event that occurs in most cases suddenly and unexpectedly, causing severe disturbances to people or objects affected by it, and resulting in loss of life and harm to the health of the population, the destruction or loss of community property, and/or severe damage to the environment. Such a situation causes a disruption in the normal pattern of life, generating misfortune, helplessness, and suffering, effects on the socioeconomic structure of a region or a country, and/or the modification of the environment, to such an extent that there is a need for assistance and for immediate outside intervention.

Disasters can be caused by a natural phenomenon, by man, or can be the result of a technical failure of industrial or military systems.

Some disasters of natural cause represent threats that cannot be neutralized since their origins can hardly be forestalled, although in some cases they can be partially controlled. Earthquakes, volcanic eruptions, tidal waves (tsunamis), and hurricanes are examples of hazards that still cannot be prevented in practice, while floods, drought, and landslides can sometimes be controlled or mitigated by applying drainage systems and stabilization of soils.

Here is an extensive list of natural phenomena that can cause disasters or calamities:

- Earthquakes
- Tsunamis (tidal waves)
- Volcanic eruptions
- Hurricanes (storms, gales)
- Floods (slow, rapid)
- Massive movements (landslides, collapses, flows)
- Droughts (desertification)
- Epidemics (biological)
- Pests

These are what might be called basic phenomena, since occasionally they generate other effects, as is the case with avalanches or mudslides, and the ash rains or lava flows that are directly associated with volcanic eruptions, or other kinds of phenomena that may be considered equivalents, such as tornados, tropical cyclones, or hurricanes. Most of these phenomena are cataclysmic, that is, they occur suddenly and affect a not very large area. However, there are cases such as desertification and drought which occur over a long period and affect extensive areas in an almost irreversible way.

Man-made disasters can either be deliberate or due to a technical failure, which can trigger a series of other breakdowns and cause a major disaster.

Other man-made disasters include:

- Wars (terrorism)
- Explosions
- Fires
- Accidents
- Deforestation
- Contamination
- Collapses (impacts)

In general there exists a broad range of possible disasters of technological origin. At present, urban centers and ports are highly vulnerable to this type of disaster due to the high density of industry, building, and mass cargo and passenger transport systems.

EFFECTS OF DISASTERS

The effects of a disaster vary depending on the characteristics of the exposed elements and on the nature of the event itself. In general, the

elements at risk are the population, the environment and physical structures in housing, industry, trade and public services.

The effects can be classified as direct and indirect losses. Direct losses are related to physical damage, expressed in the number of victims, in damage to the infrastructure of public services, damage to buildings, the urban area, industry, trade, and deterioration of the environment, that is, physical alteration of the habitat.

The indirect losses can usually be broken down into social effects such as the interruption of transportation, public services, and the media, and the unfavorable image that a region may acquire with respect to others; and economic effects such as disruption of trade and industry as a consequence of the decline in production, disincentives for investment, and the expense of rehabilitation and reconstruction.

In numerous developing countries, such as the countries of Latin America and the Caribbean there have been disasters in which thousands of people have died and hundreds of millions of dollars have been lost in twenty or thirty seconds. Often the direct and indirect costs cannot be calculated, but amount to a huge percentage of a country's gross domestic product. Due to the recurrence of different types of disasters, in several countries of the Region average annual losses due to natural disasters amount to a significant percentage of the gross national product. Obviously, this translates into impoverishment of the population and stagnation, because it entails unforeseen expenditures that affect the balance of payments and in general the economic development of a country.

If existing levels of risk are to be reduced, preventive measures against the effects of disasters should be considered a fundamental part of comprehensive development at the regional and urban level. Given that disasters of the magnitude referred to above can have a serious impact on the development of affected communities, the cost of carrying out preventive measures ought to be measured against that of recovery from disasters, and risk analyses ought to be included in the assessment of the social and economic aspects of every region or country.

CONCEPTUAL FRAMEWORK

The impact of disasters on human activities has in recent years been dealt with in a wide range of publications produced by various disciplines that have each taken a different, although in most cases similar, conceptual approach. The Office of the United Nations Disaster Relief Coordinator (UNDRO)—currently the United Nations Department of

Humanitarian Affairs (UN/DHA)—jointly with the United Nations Educational, Scientific and Cultural Organization (UNESCO) sponsored a meeting of experts for the purpose of proposing standardized definitions that have been widely accepted in recent years. The report of that meeting, which was entitled "Natural Disasters and Vulnerability Analysis" included the following definitions, among others:

Hazard (H): the probability that a potentially disastrous event might occur during a certain period of time in a given site.

Vulnerability (V): the degree of loss of an element or group of elements at risk as a result of the probable occurrence of a disastrous event, expressed on a scale from 0 or no damage, to 1, total loss.

Specific Risk (R_s): the degree of loss expected due to the occurrence of a specific event, as a function of the hazard and vulnerability.

Elements at Risk (E): the population, buildings and public works, economic activities, public services, utilities, and infrastructure exposed in a given area.

Total Risk (R_t): the number of people killed or injured, damage to property, and the impact on economic activity due to the occurrence of a disastrous event, in other words the product of the specific risk (R_s) and the elements at risk (E).

Hence risk can be calculated using the following general formula:

$$R_t = E \cdot R_s = E \cdot (H \cdot V)$$

Taking the elements at risk (E) implicit in vulnerability (V), without modifying our original approach, it could be said that:

Once the hazard (H_i) is known and understood to be the probability that an event will occur with an intensity greater or equal to (i) during exposure period (t), and once vulnerability (V_e) is known and understood to be the intrinsic predisposition of an exposed element (e) to be affected or to be likely to suffer a loss should a disaster occur with an intensity (i), risk (R_{ie}) can be understood as the probability of a loss in element (e) as a consequence of the occurrence of a disaster with an intensity greater or equal to (i),

$$R_{ie} = (H_i, V_e)$$

that is, the probability of exceeding a certain level of social and economic consequences during a given period of time (t).

Thus, we can now distinguish more precisely between two concepts that have occasionally been mistakenly considered synonymous but which are definitely different from both a qualitative and a quantitative point of view:

- ▶ *The hazard*, or external risk factor of a subject or system, represented by a latent danger associated with a physical phenomenon of natural or technological origin that may occur in a specific place and at a given time producing adverse effects on people, property, and/or the environment, mathematically expressed as the probability of a disaster greater than a certain intensity occurring in a certain place and over a certain period of time.
- ▶ *The risk*, damage, destruction, or expected loss derived from a combination of the probability of dangerous events occurring and the vulnerability of the elements exposed to such threats, mathematically expressed as the probability of exceeding a certain level of economic and social consequences in a certain place and over a certain period of time.

In general terms, *vulnerability* can be understood, then, as the intrinsic predisposition of a subject or element to suffer damage due to possible external events. As a result, its evaluation is a key part of assessing the risk derived from interactions of a susceptible element with a hazardous environment.

The fundamental difference between hazard and risk is that hazard is related to the probability of a natural or an induced event occurring, while risk is related to the probability of certain consequences occurring that are closely related not only to the degree to which those elements are exposed but also to the vulnerability of those elements to the impact of such an event.

HAZARD AND SEISMIC RISK

Earthquakes consist of sudden releases of energy due to stresses that have accumulated for years in parts of the earth's crust. The main causes of stress in the crust are found in the forces pulling at its component parts (the tectonic plates), which are countered by opposing forces in adjacent plates. Not much is known about these forces, but it is thought that they are due to either the high temperatures inside the earth, or to

the force of gravity. Earthquakes originated in this way are usually of intermediate depth or deep-seated.

The forces generated in the tectonic plates in turn produce cracks in the plates themselves, which are known as geological faults. Forces derived from tectonic activity can then arise within those faults and tend to move a sector of the fault, generating contrary forces in the opposite sector. This is the origin of the process of accumulation of displacement energy. Earthquakes caused by active geological faults are generally shallow or of intermediate depth and are consequently very dangerous.

The usual ways to measure an earthquake are related to their strength, their location, and their surface manifestations in cities or sites of interest. The energy or strength of an earthquake is measured as its magnitude, a simple numerical scale developed by Charles Richter.

Measurement of the magnitude, as well as the identification of the site at which the phenomenon occurred (epicenter) is carried out using seismographs. As such, the magnitude is a measure of the earthquake at the point at which energy was released. In places far away from the event, such energy is attenuated due to the cushioning effect of the rocks through which the seismic waves travel. It is for this reason that it is more desirable to measure the effect on sites of interest in terms of ground motion. This measurement, carried out by means of accelerometers, usually records ground movement in the three spatial directions, in terms of its acceleration, since this information tells us about the ground velocity and ground displacement.

Ground motion is, accordingly, a function of the magnitude of the earthquake, its distance from the point at which energy was released, and of the properties of attenuation of that energy associated with the geological province in which the earthquake occurs. Studies of seismic hazard seek to establish, for each site of interest, an earthquake unlikely to be exceeded in a period that is considered adequate as the average life of the building or buildings to be constructed, on the basis of available information on the seismic sources that might affect that site.

In addition to the factors already mentioned, the following can also influence the impact of an earthquake in cities:

The amplification of seismic waves by the soils. This fact is currently the object of much attention on the part of researchers, since the energy unleashed in earthquakes can be greatly amplified depending on the characteristics of the soils which support the buildings in cities. Earthquakes occurring far from a city and which are practically

insignificant on hard or rocky soils are amplified destructively when the seismic waves encounter soft soils, usually lacustrine.

Liquefaction. In certain cases, especially in that of saturated sandy soils of uniform gradation, liquefaction of the soil can occur, a phenomenon that consists in the sudden sinking of the soil because of the increase in the pressure of the water contained in the soil when a seismic vibration occurs. It can be catastrophic.

Mass movements. Mountainous land can suffer landslides or collapses as a consequence of the seismic thrust of the earth. Sometimes the mass movements do not occur immediately after an earthquake, but after several hours or days.

Ground settlement. This can occur with loose soils, or with soils supported by layers of soils that have undergone liquefaction, etc.

Tsunamis or tidal waves. Ocean waves generated by seismic activity on the ocean floor can cause floods in coastal areas and may affect areas located thousand of kilometers from the earthquake epicenter.

Indirect hazards. The force of the earthquake can cause cracks in dams, which can aggravate the effects of the disaster downstream from reservoirs, or contamination caused by damage to industrial plants, such as leaks of gases or dangerous substances, explosions and fires.

Most of the damage caused by earthquakes is due to the strong movements of the earth. Strong earthquakes have been felt in areas up to five million square kilometers. For this reason, engineering decisions are normally made on the basis of evaluations of large movements, expressed in terms of the maximum acceleration to be expected for ground movement in each site.

Central and South America, especially on the Pacific coast, are areas prone to earthquakes and present a high level of seismic hazard. Major earthquakes have occurred on the border between Costa Rica and Panama (measuring 8.3 on the Richter scale; 1904), on the border between Colombia and Ecuador (8.4 on the Richter scale; 1960), in Peru (8.6 on the Richter scale; 1942), to the north of Santo Domingo, Dominican Republic (8.1 on the Richter scale; 1946) and in Chile (8.4 on the Richter scale; 1960). In general, all the countries of Latin America present some degree of seismic hazard given that earthquakes have occurred in many provinces that may be not recalled as being particularly strong but did indeed frequently cause large-scale catastrophes and damage. Approximately 100,000 inhabitants of this region have died as a consequence of earthquakes during the 20th century, and 50,000 as a

consequence of volcanic eruptions; the number of injuries far exceeds the number of deaths.

Hospitals and health installations in general are exposed elements that can suffer serious damage as a consequence of the occurrence of strong earthquakes. Since the seismic risk to health installations can be very high, it is necessary to construct any new building with a level of seismic resistance in accordance to the seismic hazard in its area. It is also necessary to evaluate the seismic vulnerability of existing buildings, in order to identify their weaknesses and to design and carry out the alterations or retrofittings that may be necessary.

CHAPTER 2

EXPERIENCES OF HOSPITALS AFFECTED BY DISASTER

DAMAGE TO HOSPITALS

The need for health installations to be prepared and able to act in emergency situations is widely recognized in the countries of Latin America and the Caribbean as a matter of major importance. In the past, the impact of earthquakes and hurricanes along with other natural hazards, has demonstrated that hospitals and health installations can be vulnerable to these events, and are not always able to respond adequately.

For example, the planning, design and construction of hospitals in areas of high seismic activity require means for protecting the different professionals working in them, due to the importance that these facilities have in the normal life of a community and ever more so in the event of a seismic event when victims need treatment. Given the importance of hospitals for the recovery of a community hit by a strong earthquake, it is clear that numerous aspects have to be considered very carefully in their design, ranging from planning how to maintain treatment during disasters, up to the installation of equipment and various non-structural elements, including the structural capacity to resist earthquakes.

Despite those considerations, a large number of hospital have in fact suffered serious damage and even functional or structural collapse as a

consequence of natural disasters, depriving their respective communities of adequate care for the victims.

It is worth noting that many of the affected hospitals were designed in accordance with standards of earthquake-resistant construction. This leads us to believe that the structural design of hospitals should be carried out with greater care than is usually devoted to more conventional designs, and that it may not be enough simply to make structures stronger than those used for housing or office buildings. The safety considerations built into the architectural and structural design should be based not only on purely physical aspects of the disaster that could strike the building but also on the social, economic and human criteria involved in the planning of the hospital.

Table 1 presents a list of some hospitals that have suffered severe damage or structural collapse as a result of earthquakes.

HOSPITAL	COUNTRY	EARTHQUAKE
Kern Hospital	U.S.A.	Kern County, 1952
Hospital Traumatológico	Chile	Chile, 1960
Hospital de Valdivia	Chile	Chile, 1960
Elmendorf Hospital	U.S.A.	Alaska, 1964
Santa Cruz Hospital	U.S.A.	San Fernando, 1971
Olive View Hospital	U.S.A.	San Fernando, 1971
Veterans Administration Hospital	U.S.A.	San Fernando, 1971
Seguro Social	Nicaragua	Managua, 1972
Hospital Escalante Padilla	Costa Rica	San Isidro, 1983
Hospital Juárez	Mexico	Mexico, 1985
Centro Médico	Mexico	Mexico, 1985
Hospital Bloom	El Salvador	San Salvador, 1986
Hospital San Rafael	Costa Rica	Piedras Negras, 1990

TABLE 1. HOSPITALS AFFECTED BY EARTHQUAKES IN THE REGION OF THE AMERICAS

SOME ILLUSTRATIVE CASES

During the last two decades, more than 100 hospitals in the Americas have suffered severe damage and even total collapse as a result of earthquakes. For example, during the earthquake at San Fernando, California, on 9 February 1971, four hospitals suffered damage so severe

that they could not operate normally when they were most needed. Moreover, most of the victims of the earthquake were patients in two of the hospitals that collapsed. Ironically, the most dangerous places in San Fernando during the earthquake were the hospitals.

During the earthquakes of 19 September 1985 in Mexico City three of the largest health institutions in the city were seriously affected: the National Social Security Medical Center, the General Hospital and Benito Juárez Hospital. What with the number of beds destroyed and those which had to be evacuated, the earthquakes produced a sudden deficit of 5,829 beds; 295 people died in the General Hospital, and 561 in the Juárez Hospital, among whom were patients, doctors, nurses, administrative personnel, visitors and newborns.

Table 2 provides some statistics concerning post-earthquake effects on hospitals in Latin America.

PLACE AND YEAR	MAGNITUDE	GENERAL EFFECTS
Managua, Nicaragua, 1972	5.6	The General Hospital was severely damaged, evacuated and subsequently demolished.
Guatemala City, Guatemala, 1976	7.5	Several hospitals were evacuated.
Popayán, Colombia, 1983	5.5	Damages and interruption of services in the San José University Hospital.
Mendoza, Argentina, 1985	6.2	Approximately 10% of the total number of beds (state + private = 3,350) were lost. Of the 10 installations affected, 2 were demolished and 1 evacuated.
Mexico, D.F., Mexico, 1985	8.1	5 medical installations collapsed and another 22 suffered severe damage; at least 11 installations were evacuated. The direct losses were estimated at US\$ 640 million.
San Salvador, El Salvador, 1986	5.4	Over 2,000 beds were lost. More than 11 hospital facilities were affected, 10 were evacuated and 1 was totally destroyed. Estimated damage totalled US\$ 97 million.

TABLE 2. POST-SEISMIC EFFECTS ON HOSPITALS

To repeat what was stated in the introduction, in the last 20 years more than 100 hospital installations, serving an estimated population of between 10 and 12 million people in 9 countries of the Americas, have

been affected by earthquakes. Nearly one fifth of those installations collapsed catastrophically or had to be demolished as a consequence of the damage suffered during disasters. This meant a great toll in human lives and the loss of more than 10,000 hospital beds. At current costs, the replacement value of those beds amounts to more than US\$700 million. Such statistics underscore the need to review the design and criteria for the construction of hospital installations in earthquake-prone areas.

CHAPTER 3

IMPORTANCE OF HEALTH CARE FACILITIES

HEALTH FACILITIES IN DISASTER SITUATIONS

Most health services are found in hospitals, clinics and medical centers run either by the government or the private sector. Hospitals normally provide emergency, secondary, and tertiary medical services while health centers provide primary care and some basic treatment or first aid.

Health facilities play a very significant role in the mitigation of disasters because of their particular function in treating the injured and handling outbreaks of disease.

Geriatric and psychiatric hospitals are less critical relatively speaking, except when their installations are damaged or when there is a great psychological impact on individuals in the population affected by the disaster.

The fundamental role of health centers is surveillance. Historical evidence has demonstrated that an uncontrolled spread of communicable diseases after a natural disaster has been the exception and not the rule.

Some health centers are equipped to treat people with minor injuries, which is extremely useful in order to reduce congestion and referral to hospitals or other more sophisticated medical facilities.

Hospitals require special consideration with regard to risk mitigation due to the following factors:

- Their complexity and occupancy characteristics;
- Their role during disaster situations with regard to the preservation of life and good health, especially in the diagnosis and treatment of injuries and illness.

Occupancy characteristics

Hospitals may at any time find themselves full of resident patients, transient patients, staff members, employees and visitors. Hence, there are three principal reasons for having a disaster preparedness plan:

- Patients must continue to be treated during the occurrence of a hazardous event: provision must be made for the personnel and support services to be readily available at all times.
- Protection for all the occupants must be guaranteed. A vulnerability analysis of the installations must be carried out and, if necessary, the installations must be retrofitted in accordance with current requirements of design and construction. There are cost-effective ways to do this; the documents in this series contain a description of appropriate techniques for this type of analysis and alteration.
- It may be necessary, at some point during the disaster, to evacuate outpatients and resident patients. This problem can be exacerbated if the event occurs suddenly and while the hospital is full of visitors who, in most cases, are not familiar with evacuation procedures.

Visitors in this case aggravate the problem, since visiting the patients is a popular practice. In all of Latin America the number of visitors at peak periods, such as weekends, may be twice the number of resident patients. Most hospitals have companion beds which means that a high percentage of the resident patients may be accompanied at night. Evacuation plans should take into account such situations.

The hospital in disaster situations

In the event of disaster, a hospital must continue with the treatment of resident patients and serve the people injured in the disaster. To do this the personnel must be in place and know how to respond to the situation. The building and its equipment must also remain serviceable. Most hospital authorities recognize these facts, and for that reason have prepared formal plans for the mitigation of disasters. However, all these plans suffer from a lack of organizational alternatives in the event of severe damage to, or paralysis of, the facility. Little attention has been

paid to this, which is worrisome since in many places medical care depends on only one hospital, and its damage could cause an enormous crisis due to the lack of alternatives in the area.

Good systems for organizing and mobilizing personnel, equipment and supplies within a safe environment are fundamental for an effective response to the disaster. This need for systematic arrangements underscores the critical nature and interdependence of processes, buildings and equipment. Deficiencies in any of these elements of the functional system of a hospital could induce a crisis in the institution.

Processes

These mainly have to do with the mobilization of people, equipment and supplies. Organizing them includes setting up a committee to formulate measures for the mitigation of disasters. The terms of reference of the committee in charge of disaster preparedness include drawing up a formal preparedness plan for the provision of medical care, its dissemination among the personnel for the purpose of creating awareness and familiarity with the plan, training in its execution, and tests and exercises in order to evaluate the effectiveness of the plan in the face of different types of hazards. The plans should be reviewed and updated frequently.

Buildings

The plans should include organizational alternatives in the event of serious damage to the hospital installations. Previous disasters have clearly demonstrated that this is a defect in existing plans. Experience indicates that factors have to be incorporated into the design and construction of buildings that will not only insure safety but will also preserve certain critical areas of the hospital, such as the emergency department, the facilities needed for diagnosis, operating rooms, the pharmacy, food and medicine storage areas, and registry services.

In the past, the emphasis in hospital design was on the optimum allocation of space and the arrangement of services in such a way as to ensure the best possible interrelationship between the functions and activities of the different departments. New hospitals with modern design and construction techniques have also proved to be vulnerable due to defects in the functional distribution of sectors in the event of the need for massive treatment of injured people, as well as to defects in their non-structural components. Many installations fail due to simple

omissions in their design, which could have been corrected at a marginal cost during the construction or alteration of their existing structures.

Equipment

The contents of buildings cause more problems when earthquakes occur than when hurricanes occur. Much damage can be prevented by applying simple and inexpensive measures, such as securing shelves to the walls and placing plant and equipment in strategic and safe positions. Regular inspections and appropriate maintenance of such elements could also ensure that they will always be operational and in good condition. It would suffice to bear these things in mind when carrying out normal, periodic maintenance of the building, its installations and components.

ECONOMIC AND SOCIAL COSTS

Health is usually understood as an individual right and a right pertaining to the entire community. For this reason, in many countries health installations are owned by the State and run by the government. In most cases health is financed by revenue generated mainly from taxes, which is why public health services are provided at low cost or free of charge and depend on the economic capacity of the governments. In other words, since health institutions are the result of government investment, their survival depends on the state of the economy of the government.

Any adverse impact on the economy of a country will affect its ability to provide health services. Moreover, due to the importance and high cost of hospital facilities, severe damage to them will not only affect the productive capacity of a country but will also erode public finances due to the cost of rehabilitation and reconstruction.

In recent years, much capital has been invested in expansion of hospitals and in alterations designed to reduce vulnerability despite the fact that this capital generates no income and can become an added burden to the government in meeting the recurrent expenditures to keep the facilities running properly. This makes it all the more important to ensure that all investment in social programs, particularly in times of economic difficulty, is properly safeguarded and not at the mercy of natural disasters.

CHAPTER 4

VULNERABILITY OF HOSPITALS

VULNERABLE ASPECTS OF HOSPITALS

Hospitals are essential for dealing with a disaster, but they are also highly vulnerable installations. Perhaps there are other buildings and installations of equal size and construction in a city, but not as complex from the functional, technological and administrative point of view. The factors that make hospitals especially vulnerable include:

Complexity. Hospitals are very complex buildings that combine the functions of a hotel, offices, laboratory and warehouse.

The hotel aspect alone is highly complex since it involves not only lodging, but food services for a large number of people, including patients, employees and visitors. These centers usually contain numerous small rooms and many long corridors. After a disaster, the patients and visitors will be very confused. There may be a power outage. The corridors and doorways of the rooms may be blocked by fallen furniture or rubble. The elevators will not work and staircases may have collapsed or be difficult to use.

Occupancy. Hospitals are densely occupied buildings. They lodge patients, employees, medical personnel, and visitors 24 hours a day. Many patients require constant assistance and specialized care and may

be surrounded by special equipment and perhaps utilize potentially dangerous gases such as oxygen. Patients might be connected to life-support equipment which requires electric current at all times.

Critical supplies. Most of the supplies that hospital installations require (medicine, splints, bandages, etc.) are essential for the survival of the patient and they are crucial for the treatment of earthquake victims. Patients' case-history files are vital if they are to get proper treatment, especially if they are evacuated to other centers. Damage to storage and file areas will make it impossible to obtain these documents at the time they are most needed.

Public services. No institution depends more on public services than hospitals. Without electricity, water, fuels, refuse collection, communications, and free access to and from them, hospitals could not function. X-ray equipment, monitoring equipment, life-support services, sterilization, and other equipment all require electricity.

The complex organization of health care installations means that internal and external communication systems are crucial.

Larger health facilities depend on elevators for moving both people and supplies. Even in a moderate earthquake, for example, elevators will remain out of service until they can be inspected for possible damage.

Dangerous materials. Several products used in a hospital are dangerous if they are spilled or leak. Shelves full of medicine or chemicals that are overturned can release poisonous liquids or gases. Fires may be started by spilt chemicals and overturned gas cylinders or ruptured oxygen supply lines can pose serious threats. In addition, some drugs may fall into the wrong hands once safety controls break down.

Heavy articles. Many hospitals have equipment or televisions on high shelves above or near the beds of the patients; these can fall and cause serious accidents. Other pieces of specialized equipment, such as X-ray machines or emergency generators, are heavy and capable of being overturned or thrown across a room during an earthquake.

External problems. In addition to these internal problems caused by damage to the hospital itself, the damage suffered by the local community may delay the arrival of firemen, the police, and, perhaps, disrupt the telephone service, at the same time that an unprecedented number of injured are arriving. There will also be crowds seeking information about patients in the hospital. Just when it is most needed, the building may cease to be functional, and medical personnel may be killed or injured.

**FUNCTIONAL
VULNERABILITY**

From the functional point of view, we should mention a hospital's external characteristics such as the selection of the land, its size, the public services available, environmental restrictions, adjacent roads and their connection to the urban street network. It is also necessary to deal with general physical layout, that is, with the interrelationships between areas, with the primary and secondary, private and public corridors within the hospital, and with public and private access to the basic areas which make up the hospital. Finally, one should take into account physical layout in areas not open to the public, that is, the internal functioning of each of the five sectors that make up the hospital.

A hospital building is composed of five basic areas, each of which has very specific functions, but which in turn must interact with other areas in ways which are vital if a hospital is to operate properly. The relations between such areas or sectors—Administration, Ambulatory Care Units, General Services, Outpatient Consultation and Emergency Services, and Inpatient Care Units—can be critical if the original design failed to consider their function and distribution in the case of a sudden influx of patients. A hospital can suffer a "functional collapse" as a result of this situation, which is only detected at the time an emergency occurs. In addition to the above-mentioned areas, it is important to have an external services area, which plays a particularly important role in dealing with disasters.

**NON-STRUCTURAL
VULNERABILITY**

A building can remain standing after a disaster but still be unserviceable due to non-structural damage. The cost of the non-structural elements in most hospital buildings is considerably higher than that of the structural elements. This is especially true of hospitals where 85% to 90% of the value of the installation is not in the support columns, floors and beams, but in the architectural design, mechanical and electric systems and in the equipment contained in the building. A relatively minor seismic movement may cause more non-structural damage than damage to structural components. As a result, the most vital aspects of a hospital, those that are most directly related to its purpose and function, are those most easily affected or destroyed by earthquakes. Conversely, it is easier and less expensive to adapt them and prevent them from being damaged or destroyed.

It does not suffice to ensure that a hospital simply does not collapse after an earthquake; it must continue to function as a hospital. It may continue to look like a hospital, but if it is critically affected internally,

it cannot provide proper medical care. This section focuses on the need to prevent an "internal disaster" or what is technically known as "non-structural failure". It also refers to the non-structural failures that may affect the integrity of the structure itself.

Architectural elements

With regard to architecture, the specific points to be looked into are unreinforced masonry fill-in and heavy veneers. Although unreinforced masonry fill-in is not usually considered to be a structural element, it does give rigidity to a building until it begins to fall. If these segments of internal partitions fail irregularly, they may cause stress on the columns and beams that was not foreseen in the design.

If one side of the building loses a large part of its heavy veneer exterior while another side does not during an earthquake, the imbalance may cause the building to twist. This torsion may not have been foreseen in the structural calculations and could result in partial collapses.

In buildings with platforms, account should be taken of the impact on the lower diaphragms if the architectural components of the upper floors come loose and fall.

Another architectural problem that may affect the structure of a building is known as "the short column effect." Sometimes buildings are designed with a ground floor that includes a great quantity of open space between support columns. Their engineering should be adapted in order to enable them to resist earthquakes by ensuring that ground level columns are strong and flexible enough. Sometimes these buildings are remodeled later on in order to close those open areas with filler masonry up to a certain level, just leaving space for windows in the upper part. This confines the lower part of the columns and, essentially, shortens their effective length. It is known that such "short columns" give way in earthquakes because the flexibility and resistance with which they were originally constructed have been altered.

Installations and equipment

Incidents observed in previous earthquakes can illustrate the type of problems that may arise:

- Overturned oxygen or inflammable gas cylinders, with highly dangerous leaks.
- Overturning of the emergency generator due to the corrosion and weakness of the fixtures anchoring it, causing a power outage and creating a fire hazard.

- Total or partial overturning of high-voltage transformers and spilling of oil, also causing power outages in the emergency power supply system and a potential fire hazard.
- Displacement of the telephone communications control panel, causing a temporary interruption in a hospital's communications.
- Overturned storage shelving and breakage of flasks in cupboards causing the loss of their content and consequently the loss of badly needed medicine.
- Falling laboratory equipment and breakage of such instruments as microscopes and computers.
- Broken cables and falling of elevator counterweights.

As regards mechanical installations, there have been cases in which the structural walls that were part of an earthquake-resistant design were opened up in order to install air-conditioning units. This may not have happened during the original construction of the building, but later when the original design engineers were no longer associated with the construction. These openings weaken the structural walls, which could result in failures or a partial collapse during an earthquake, even though the initial design was earthquake-resistant.

STRUCTURAL VULNERABILITY

It is easy to conclude that hospitals have more problems being prepared for a disaster than any other service. Many of the problems mentioned previously stem from deficiencies in the structural and non-structural safety of the building. In the case of a new building, the structural component should be considered during the design and construction stage, or in the case of an existing building, during repair, remodeling or maintenance. A good structural design is crucial if the building is to withstand a severe earthquake. The building may be damaged, but it is unlikely to collapse. If a hospital collapses even partially, it will be a liability for the community after the disaster and not the asset that it should be.

Moreover, in the planning of a hospital it is necessary to take into account that one of the most common causes of damage in buildings is a hazardous architectural-structural configuration. Departure from simple structural schemes can turn out to be a costly decision when it comes to earthquakes. In addition, unfortunately, the usual methods of seismic analysis fail to quantify most of these problems correctly. Given the erratic nature of earthquakes, as well as the possibility that their

magnitude will exceed that envisaged in a building's design, it is advisable to avoid proposing hazardous configurations, regardless of the degree of sophistication that it may be possible to achieve in the analysis of each particular case.

Unfortunately, in many countries of Latin America seismic-resistant construction standards have not been effectively applied and in others such standards have not taken into account specifications unique to hospitals. Thus, it is hardly surprising that every time that an earthquake occurs in the region the buildings worst hit are precisely the hospitals, which should be the last to be affected. Because the structural vulnerability of hospitals is in general high, this situation should be corrected totally or partially if enormous economic and social losses are to be avoided, especially in developing countries.

EVALUATION OF VULNERABILITY

In the case of health facilities it is necessary to evaluate their vulnerability to natural hazards at the local level in order to obtain precise estimates of the degree of risk that they face. Once this type of analysis has been completed, the information obtained allows a decision to be taken on an acceptable level of risk.

A vulnerability analysis could begin with a visual inspection of the facilities and with the preparation of a preliminary evaluation report. Such an inspection makes it possible to identify areas that require attention. The report can be discussed with the consultants and the authorities in charge of the facility with a view to defining priorities and timetables for the work to be carried out. Once the retrofitting program has been designed, other reviews and studies should be carried out in specific areas identified as being in need of modification.

Functional aspects

The first aspects that should be confirmed when evaluating functional vulnerability are those related to infrastructure. This includes the external physical resources on which the hospital depends, such as communications, water supply, sewage systems, energy, and the information network of the facility.

Telephone lines may be seriously damaged by natural disasters. This can occur even though underground lines are not susceptible to hurricanes and they are, normally, sufficiently insulated and flexible enough to resist damage caused by floods and earthquakes.

The main water supply system, which normally consists of pumping stations, water treatment plants and underground pipes, may be interrupted because of damage to the pumping mechanisms or, more frequently, because of broken pipes. For this reason, hospitals should have water storage tanks that are incorporated into the daily supply system in order to guarantee that the water is in good condition at the moment the emergency occurs.

The power supply system, which consists of electricity generators, high tension wires, underground plants, and equipment located on the ground, are the most vulnerable parts of this system. The transformers and porcelain insulators are the weakest points, because damage to them can start fires. Poles supporting power lines and cables are particularly vulnerable to strong winds. It is therefore advisable for health facilities to have emergency generators ready to operate at any time.

During earthquakes, the vulnerability of water, sewage, gas and fuel pipelines depends on their resistance and flexibility. A high degree of flexibility of the pipes can avoid breakage during a moderate earthquake; settling may be compensated for and the displacement of the soil will not necessarily lead to breakage. Special attention should be given to connections inside buildings, which need to meet special design requirements.

Other special measures to mitigate the effects of disasters in hospitals are of great importance. Signs and orientation maps on each floor should be clear and easily recognizable by visitors; the fact that electric current may be cut off must be taken into account; elevators should not be used even if they remain operational; the stairs should be used to get downstairs even though, in the case of an earthquake, some rubble may fall since the rigid elements between floors are subjected to heavy loads and are likely to suffer damage; the doors can get stuck due to the movement of the building and may make it difficult to get out of the facility. It should be emphasized that even when no non-structural damage occurs and the hospital can continue operating it is necessary to have a structural inspection done immediately by professionals specially trained for this purpose.

A detailed analysis of the outlying areas, of hospital access routes and of the interrelationship between the sectors that together make up the services provided by a hospital can lead to recommendations for functional redistribution and for the layout of certain areas that would prove particularly useful in emergency situations involving large numbers of patients.

Non-structural aspects

Non-structural elements include non-load bearing exterior walls, dividing walls, interior partitions, windows, ceilings, elevators, mechanical and electrical equipment, lighting systems, and other internal components. Non-structural damage frequently causes enormous losses, particularly as a result of earthquakes. Damage to non-structural components can be severe and can paralyze a hospital, even when the structure of the building remains intact.

The cost implications of such damage can be high, given that the structure of the building only represents between 15% and 20% of the total cost of the facility. As a result, the more vulnerable non-structural elements are to earthquakes and to other natural hazards the greater the risk for the occupants and the probable losses.

A breakdown in hospital services can be aggravated because design codes do not normally take into account specific requirements for the design of mechanical and electrical systems. Experience has demonstrated that secondary effects of non-structural damage can significantly aggravate the situation. For example, ceilings and wall finishings that fall into corridors or stairwells can interrupt the flow of people. Fires, explosions, and chemical leaks can endanger people's lives.

Much of what is to be found in health facilities is essential for their operation. Expensive equipment for patient registration is crucial immediately after an earthquake or a hurricane. Construction codes do not cover this type of equipment, which is why preventive measures should be taken by health administrators and managers.

In many cases, people without specialized training can carry out a preliminary evaluation of the level of risk by bearing in mind two basic questions for each non-structural element under consideration:

- Could this element be damaged in an earthquake?
- If it were damaged would it cause a serious problem?

This will produce a preliminary list of elements for more detailed consideration. At this stage it is preferable to be conservative and to overestimate vulnerabilities.

Structural aspects

Since many hospital buildings are old and others were neither designed nor constructed to resist earthquakes, there are doubts as to whether they are safe enough to perform properly in the event of an earthquake. Such doubts are particularly worrisome in the case of those hospitals that are needed in a seismic emergency and have nevertheless

been designed only in order to support their own weight. In those cases what is urgently needed is as detailed a review as possible of the capacity of the structure to withstand moderate and strong earthquakes. One should bear in mind that the difficulty of constructing new hospitals in seismic areas, due to their high cost, makes strengthening existing health facilities all the more important. Before any action is taken, there should be an analysis of the existing capacity to resist and absorb earthquakes, as well as of the functional, organizational, and administrative vulnerability of the hospital.

Buildings essential for post-seismic recovery call for especially careful analysis. There are analytical and experimental methods available for this purpose. The latter determine the dynamic behavior of the structure by direct measurement of environmental vibrations but have the disadvantage of only providing information about the dynamic characteristics of the construction under minor vibrations. These measurements are insufficient when it comes to answering queries about resistance, dissipation of energy, etc., and should be complemented with purely analytical methods.

In Latin America, the buildings are usually made of reinforced concrete, brick masonry or wood with light roofs. The assessment of the structural vulnerability of these types of buildings should be carried out by specialized engineers.

The evaluation of the condition of an existing construction can give rise to serious doubts about its capacity to withstand seismic events. Some countries of the Region have launched campaigns to retrofit existing buildings in order to reduce their vulnerability before a disaster occurs. In principle, where hospitals are evaluated and determined to be inadequate to resist seismic and other natural hazards, one would conclude that reducing vulnerability should be compulsory since these facilities are essential for handling emergencies.

CHAPTER 5

RISK MITIGATION IN HOSPITALS

REDUCTION OF EXISTING VULNERABILITY

The level of risk can be reduced if it is understood as a combination of the hazard or probability of occurrence of disaster and the vulnerability to it of the elements exposed, or as an estimate of the severity of the possible impact on those elements. Structural measures such as the construction of protective works or alterations designed to diminish the vulnerability of the elements at risk, and non-structural measures, such as regulating soil use, incorporating preventive aspects into investment budgets, and making preparations for providing medical care during emergencies can all reduce the impact of a disaster on a region or a population.

All this should be done before a disaster occurs. Everything that is done to reduce or prevent the damages that a disaster may cause is called "mitigation of risks." Everything done afterwards is known as "response." This section focuses only on mitigation in the case of health facilities, and, in particular, hospitals.

Mitigation of the impact of disasters by the adoption of preventive measures is a highly cost-effective activity in areas where disasters are frequent. For every dollar well spent on mitigation before a disaster occurs, much more will be saved in terms of losses prevented. Mitigation

is not, in fact, a cost. In the long run it pays for itself. And it does so in real money, and in lives saved.

Functional alterations

Traditionally, functional distribution of areas within hospitals does not include as one of its design criteria the treatment of large numbers of injured persons. If this aspect is taken into account, certain adjustments can be made in the relationship between areas and, in some cases, it will be necessary to make some design changes that could help mitigate disasters in the building.

Not only for purposes of mitigation and prevention, but also for administrative reasons, the possibility of separating the general services sector from the main hospital building should be explored, for the following reasons:

- The general services sector usually houses boilers, which can become dangerous time bombs capable of doing untold damage should they explode.
- Similar considerations apply to a hospital's gas plant. Although it is true that this modification would be costly, when compared with the costs of the damage that could be avoided the costs involved should be considered minor.
- Another service commonly located in this sector is the emergency generator. This is a service that could also be housed in a separate building, not so much because of the risks associated with it but in order to ensure that it can be used at critical moments.
- For the same reasons, it may also be advisable to put telephone, radiocommunication, and other facilities in this separate area. As with the electric generator, this would enhance the possibility of such services being available after a disaster.
- It also is desirable to locate a hospital's water storage tanks in this area, whenever possible. In most cases they are located on the upper floors of buildings, increasing the load on the structure, and thereby constituting one more risk.
- It follows that it also would be desirable to put kitchen services in the same area, given that they require water, light and gas.
- If the same thing were done with the laundry service that would complete the package of services available and in operation, capable of serving either all or some areas of the hospital affected by a disaster or in the case of the need for an open-air hospital.

Such modifications are possible if there is a multidisciplinary team made up of engineers, architects, planners, etc., as well as medical and paramedical personnel, striving to work out a set of actions, responsibilities, movements and physical solutions. Obviously this is more feasible in the case of new designs, but it can also be implemented in certain types of existing installations.

One of the most important aspects from the functional point of view is proper posting of signs inside the hospital. This is important not only to guide people during normal use of hospital services, but for also the evacuation of the building when a disaster occurs. The signs should point to evacuation routes leading to stairs or emergency exits not normally used but designed especially for emergencies. In addition, there should be signs pointing to fire extinguishers, hoses and other fire equipment, fire doors wherever they exist, emergency telephones, etc. Signs should be posted not only inside the building, but outside and in the surrounding urban area.

Non-structural alterations

After identifying a non-structural element that can suffer or cause damage, and its priority either functionally or in terms of loss of human lives or of property, appropriate steps should be taken to reduce or eliminate the danger. We list below 12 applicable mitigation measures which, in many cases, has been shown to be effective:

- | | |
|----------------------------|-------------------------------|
| 1. Removal | 7. Substitution |
| 2. Relocation | 8. Modification |
| 3. Restricted mobilization | 9. Isolation |
| 4. Anchorage | 10. Reinforcements |
| 5. Flexible couplings | 11. Redundancy |
| 6. Supports | 12. Rapid response and repair |

1. Removal is probably the best mitigation option in many cases. For example, a dangerous material that could be spilled could be stored off the premises. Another example would be the use of heavy stone or concrete veneer on the outside of the building or along some balconies, which could easily come loose during an earthquake endangering everything beneath it. One solution would be to use better anchorage or stronger supports, but the most effective solution would be removal and substitution.

2. Relocation would reduce danger in many cases. For example, a very heavy object on a shelf could fall and cause serious injury, or it

could become damaged, causing economic losses. If the object were to be relocated to a floor level shelf, it would not endanger human lives or property. It is also advisable to keep bottles containing dangerous liquids on the floor, if possible.

3. Restricting movement of certain objects, such as gas cylinders and electricity generators, is a good measure. It does not matter if cylinders shift so long as they do not fall and break their valves, releasing their contents at high pressures. Sometimes it seems desirable to install emergency generators on springs in order to reduce the noise and vibrations when they are operating, but the springs would amplify seismic tremors. Restrictive supports or chains should be placed around such springs in order to keep the generator from shifting or being knocked off its stand.

4. Anchorage is the most widely used precaution. It is a good idea to fasten objects with bolts or to tie them down using cables or other materials to keep objects of value or of considerable size from falling or sliding. The heavier an object is, the more likely it is to move owing to forces of inertia. A good example would be a water heater, of which there may be several in a hospital. Since they are heavy and if they fall could break a water main, an electric wire or a pipe carrying fuel, they constitute a fire or flood hazard. A simple solution is to utilize metal strips to fasten the lower and upper parts of the heater against a wall or other support.

5. Flexible couplings are sometimes used between buildings and exterior tanks, between separate parts of the same building and between buildings. These are utilized because separate objects each move independently in response to an earthquake, some move rapidly or at high frequencies, others slowly at low frequencies. If a tank is connected to a building by a rigid pipe, the tank will vibrate at frequencies and in directions and amplitudes different from those of the building, causing the rigid pipe to break. A flexible pipe would prevent ruptures of this kind.

6. Supports are appropriate in many cases. For example, ceilings are usually hung from cables that withstand only the force of gravity. When submitted to the multitude of horizontal and distorting forces that result from an earthquake, they fall easily. Although electrical boxes are not heavy, sometimes they may have heavy lights fixtures attached to them. If they fall, they can seriously injure the people underneath. The electric connections may also be torn out of the ceiling and constitute a fire hazard.

7. Substitution by something that does not represent a seismic danger is the correct solution in some situations. For example, a heavy tile roof not only makes a building heavy, but also more susceptible to the movement of the earth in an earthquake. The individual tiles tend to detach themselves creating a danger for the people and objects below. A solution would be to switch to a lighter and safer roof.

8. Modification of an object that represents a seismic hazard is feasible. For example, the movements of the earth twist and distort a building, possibly causing the rigid glass of its windows to shatter, throwing sharp glass splinters at the occupants. Clear plastic can be used to cover the internal surfaces; it is invisible and reduces the likelihood of a glass window causing injuries.

9. Isolation is useful for small loose objects. For example, if lateral panels are placed on open shelves or latches on cabinet doors, their contents will remain isolated and will probably not be thrown about in the event of an earthquake.

10. Reinforcements are feasible in many cases. For example, an unreinforced fill-in wall or an unreinforced chimney can be strengthened at no great cost by covering the surface with wire mesh and by filling it in with cement or some other mixture. Not only will these non-structural objects be protected against failures; in the case of the fill-in walls the structural elements will also be strengthened.

11. Redundancy of supplies is advisable for emergencies. It is possible to store additional quantities of certain products in boxes in places that will be accessible after an earthquake.

12. Rapid response and repair is a mitigation tactic often used for long pipelines. Sometimes it is not possible to do anything to prevent a pipe breaking in a given site, so parts are stored nearby and the necessary arrangements are made to ensure rapid access to the area in case of rupture of the pipeline during an earthquake. In a hospital, spare parts for plumbing, electricity, and other repairs, together with the appropriate tools should be kept on hand, so that if something is damaged, it can easily be repaired. For example, during an earthquake water pipes may burst; it may be impossible to couple each of the tubes and take each one of the measures necessary to eliminate this risk altogether, but it should be possible to ensure that everything necessary for a quick repair is at hand. By planning before an emergency it is possible to save the enormous cost of damage caused by water with a minimum investment in a few articles and by thinking in advance about what could occur.

The general measures discussed above are applicable to almost all situations. However, in many cases, one simply has to be creative and think up one's own way to mitigate the effects of disasters.

Structural alterations

In most countries there already exists some awareness of the importance of health facilities being properly equipped to meet future needs. Many of these facilities are probably vulnerable in variable degrees to damage from earthquakes, hurricane winds, or other natural hazards. However, it is possible to reduce that vulnerability. Experience shows that applying relatively inexpensive measures has increased safety and improved existing structures. To be really efficient and beneficial, the adaptation or alteration of existing installations should be carried out systematically and consistently.

Many existing buildings do not meet the current technical requirements. Their vulnerability to certain natural hazards can be so great that associated risks may far exceed currently accepted levels. Remedial action based on scientific knowledge should, therefore, be taken in order to reduce the risk and guarantee that buildings behave as they should. Likewise, this adaptation or strengthening of existing buildings should be consistent with current engineering requirements and in accordance with the requirements established by the design codes of each country.

The usual methods for retrofitting existing structures generally include the insertion of the following elements:

Walls on the outside of the building. This solution is usually used when space limitations and continuity in the use of the building make it preferable to do construction work around the building. In order to ensure the transmission of seismic forces from the old structure to the new structural walls, beams are used at the edge of each slab.

Buttresses. Unlike the previously mentioned walls, they are placed perpendicular to the face of the building. Apart from stiffening the building, they are useful in order to keep tall buildings from tipping over. Due to space limitations, however, they are not always feasible.

Walls in the interior of the building. If conditions permit construction work inside the building, these are an alternative that must be considered in the case of long buildings, in which the structural flexibility of the floors is to be reduced. These walls are usually inserted by means of perforations in the plates of the floors through which the reinforcement bars of the new structural elements are passed.

Portico fill-in walls. Both on the inside and the outside of buildings, a practical solution to the problem of rigidity and resistance is the filling in of empty portico spaces with concrete or strengthened masonry walls. Because they are joined to columns, the stresses borne by the latter will change substantially. If the reinforcement steel in the columns is strong enough to support the new loads, the connection to the wall may be made using soldered braces only. If not, the columns will have to be sealed monolithically within the wall.

Specially anchored frames. Another frequent solution consists of including several steel frames with diagonals firmly anchored to the floors, as a substitute for the rigid walls. Also, diagonals only, joined to existing porticos, can be constructed when the porticos prove capable of withstanding the stress placed on them by the new system.

Covering of columns and beams. Used for portico systems, this technique is usually applied to most of the columns and beams of a building, in order to increase their rigidity, resistance and ductility. These systems are mostly differentiated basically by the way in which the new covering is connected to the existing column.

Construction of a new frame system. Sometimes it is possible to carry out a total restructuring by attaching the old structure to new external parametric frames. Usually this is combined with the incorporation of internal structural walls perpendicular to the longitudinal direction of the frames.

There are several reasons why altering the seismic vulnerability of the structure of a hospital building is usually more complex than a similar operation in another type of building:

- Normally the building cannot be vacated in order to carry out retrofitting.
- The scheduling of the construction work must take into account the need to keep different medical services operating, and to avoid seriously disrupting hospital activities or unjustifiably interrupting certain types of services.
- The need to perform a large number of unforeseen tasks due to the difficulty of identifying in advance precise details of the construction process.
- The complexity of the non-structural elements and the difficulty of identifying changes or effects on architectural elements prior to the beginning of the structural alteration.

It follows from the above that should be based on a very detailed work plan that includes keeping medical services going at each stage of

the process. In the same way there must be coordination between administrative personnel, the medical staff, and the maintenance department of the hospital.

It is not possible to know the cost of reducing the vulnerability of a hospital unless there is a detailed design of the structural solution and of its implications with regard to non-structural elements. However, this does not preclude drawing up a plan in advance with enough precision to ensure that it will only require minimal adjustments as the work proceeds.

Usually reinforcement costs are relatively high if they are carried out all at once. However, if the work is carried out by stages, it makes it possible for funds to be assigned more gradually and more in line with a hospital's maintenance budget.

Cost-benefit ratio

In general, it is possible to divide mitigation recommendations into two categories:

- Those that are easy to implement in the short term, for example providing windows with shutters and extra locks for doors; installing additional fasteners to roof tiles; fixing external plants; or relocating storage systems to safe buildings if the building where they are is vulnerable. These tasks should be carried out by the maintenance staff of the health center or by small contractors.
- Those that require the advice of specialists or major capital investment, such as expensive modifications or new constructions to be built in the medium and long term.

In many cases, it is up to the maintenance staff to take such steps, which can be an advantage given their knowledge of the site and their ability to carry out periodic reviews of the measures adopted. Indeed, the improvement of existing buildings and structures can be carried out through routine repairs and maintenance.

The additional costs involved in making a building resistant to hurricanes, earthquakes, and floods can be considered a form of insurance. Comparative studies show that the difference in costs between a building constructed according to anti-seismic specifications and a similar building where the code has been ignored may vary by between 1% and 4% of the total cost of the building. If the cost of the provision of the hospital's equipment is considered, the percentage could be much

lower, because equipment costs may represent around half the total cost of the building.

If one analyzes the problem in terms of the cost of protecting a specific piece of equipment, the difference could also be surprising. For example, a power outage in a hospital as a consequence of severe damage to an emergency generator which could cost US\$50,000 to repair, can be avoided by installing seismic insulators and other fixtures to keep the generator from overturning, the cost of which may be as little as US\$250.

The high economic and social returns of improving the structural behavior of vulnerable hospital buildings have been demonstrated. The cost of retrofitting, although it may seem high, will always be significantly less than the services budget or the alternative cost of repairs or physical replacement. Some good figurative questions to ask might be, how many scanners could be bought for an amount equivalent to the cost of retrofitting? And how many scanners does the hospital have? The replies could yield surprising results, without taking into account all the other elements, equipment and goods that the building normally contains, not to mention the human lives involved directly or indirectly and, in general, the social cost of a loss of hospital services.

NEW DESIGNS FOR HOSPITALS

Health centers have special characteristics as regards occupation, complexity, critical supplies, dangerous substances, dependency on public services and continuous interaction with the external environment. Since natural disasters are infrequent, very often they are ignored in the planning and design of hospitals and of other related installations, even in regions where the risks are well known. It is possible to predict with accuracy what may happen in an installation as a consequence of earthquakes or other types of disaster, but given the great variety of activities that may be underway in a hospital, it is necessary to carry out a careful analysis of possible scenarios in order to avoid a chaotic interruption in hospital services.

An unsafe building may suffer structural damage or even collapse. If such a collapse occurs the disaster is greater, since the hospital becomes a problem requiring a great deal of attention rather than an institution providing support for the affected community. Serious damage may lead to a complete evacuation of the hospital and, as a result, to loss of hospital services for a prolonged period of uncertain duration.

Architectural design

The conceptual design of a hospital involves making a series of decisions, including:

- Location of the building;
- Functional relations between hospital sectors;
- Geometry, shape or composition of the building;
- Structural system;
- Building materials.

These are decisions that should be taken jointly in the early stages of the execution of the project by the owners, health administrators, physicians and other medical personnel, architects, engineers, builders, and all those professionals who for some reason are involved with its conception and execution.

One should emphasize that, due to the complexity and close relationship to the spatial and formal layout of the construction, the problems of configuration should be tackled at the stage of preliminary definition of the spatial layout of the building, and throughout the formal and structural design stage. Thus, configuration is a subject that should be grasped in all its breadth by the designers and architects.

The seismic design of hospitals is a responsibility shared by the architects and the engineers. In particular, it is necessary to emphasize that it is shared with regard to the physical relationships between architectural forms and resistant structural systems, and it would be ideal if every designer working in disaster-prone areas understood those relationships. Unfortunately, international educational methods and practice have tended to reduce incentives for promoting this broad approach in a designer's way of thinking since training for new architects is separate from that given to new engineers and, in many cases, they remain distinct in practice. As it happens, some architects, by intuition or because of their intellectual background, have an excellent sense of structure, but this understanding on their part tends to occur despite their education and practice.

The costs involved are determined by construction techniques, the availability of materials, the nature of the equipment used, labor, and the time taken in construction, which is the reason why in some countries the responsibility for monitoring costs is entrusted to people trained in other disciplines, such as field supervisors. However, ideally, designers should from the beginning be able to count on a professional or a group of professionals who can integrate all aspects that have to be taken into account, among which are the requirements for dealing with natural

disasters. In other words, the ideal would be to have a conceptual designer with sufficient experience in architecture, engineering, costing and construction, to enable him or her to consider aspects with which to achieve maximum efficiency in design.

Design requirements in engineering

Although this document does not attempt to be a manual on design for engineers, it is important to indicate that many problems in the design of health installations can be recognized by the owner of the services, the administrator, the planner, the architect or the engineer. They can also recognize the factors that may substantially increase the seismic risk of existing buildings or of the new ones to be constructed. These factors are:

- An appropriate evaluation of the seismic hazard, including the local conditions of the soil. The harm done to a building depends both on its resistance and the type of soil it is built on and the intensity and the characteristics of the seismic movement itself.
- The design of new health installations in accordance with the requirements of the seismic building codes of each country attempts to guarantee an acceptable level of safety from the economic and social point of view.
- The administrators of health facilities should consider how to implement additional performance requirements for earthquakes in order to protect the occupants and the internal components of the building.

It is suggested that seismic performance should be guided by the following objectives, in the case of health facilities:

- The damage caused by strong earthquakes should be reparable and should not be a threat to life.
- Patients, personnel and visitors should be protected during an earthquake.
- The emergency services of the health center should remain operational after the earthquake.
- The occupants and rescue and emergency personnel must be able to move about safely inside the installations.

These objectives attempt to guarantee that the is able to fulfill its role by putting into effect its emergency plan following a disaster.

The loss of life and property caused by earthquakes can be avoided by applying existing technologies and without going to enormous expense. The only thing that is required is the will to do it. Since around

two generations are required before the current inventory of buildings in most communities gets replaced, as much attention must be paid to the structural improvement of existing buildings as to the design and construction of new buildings. At this time there exist very few technical limitations on the design and construction of most buildings to enable them to resist hurricanes, earthquakes, or other natural hazards which means that it is possible to minimize risks and damage if preventive measures are incorporated into the design, construction and maintenance of new health installations.

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