MITIGATION OF DISASTERS IN HEALTH FACILITIES

ARCHITECTURAL ISSUES

VOLUME 3

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 III: ARCHITECTURAL ISSUES

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Regional Office of the
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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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On cover: *The earthquake that jolted Mexico City on 19 September 1985 was the strongest one recorded in Latin America in the last hundred years. This earthquake killed and wounded thousands and caused severe structural damage. Health sector institutions also suffered tremendous blows, among them the General Hospital of the National Medical Center of the Mexican Social Security Institute, shown in the photo.*

Photograph: Julio Vizcarra/PAHO

INTRODUCTION

The planning, design, and construction of hospitals in areas prone to natural hazards pose many challenges to the various professionals involved not only because of the hospitals' importance in normal city life but also because of the importance they assume if the victims of a disaster must be cared for. Given the significance of hospitals for the recovery of an affected community, for example in the event of a strong earthquake, careful consideration should be given to a wide range of factors, from planning disaster response to installing equipment and various non-structural equipment and elements, in addition to the requirements of structural resistance and safety.

Despite the foregoing, many hospitals have suffered serious damage or have undergone functional or structural collapse as a result of disasters, in particular in the case of intense earthquakes, thus depriving the respective communities of adequate care for victims.

There is a need to review existing standards for the design and construction of hospitals, orienting them towards the mitigation of disasters, and the possibility of suggesting a series of changes in hospital infrastructure, from conception through to the actual construction and operation of the building.

This document aims to present a series of considerations on the criteria governing architectural design of health infrastructure and offers recommendations that should be discussed by participants representing various disciplines on ways to mitigate risk both to the population and to the investment made in construction of health facilities.

Chapter 1 of this manual examines briefly the concepts relating to the characteristics of disasters, in particular seismic hazard. Chapter 2 deals with general considerations relative to the architectural design of hospital buildings. It reviews the criteria governing design, emphasizing the necessity for teamwork among professionals from a myriad of disciplines if a coordinated approach to meeting the needs of the insfrastructure is to be achieved.

Chapter 3 discusses design changes that can be considered for disaster mitigation. By making adjustments in their design standards, new as well as existing hospitals can adapt their traditional schemes to come up with solutions that from a physical-functional standpoint enable them to better respond in times of disaster.

Chapter 4 analyzes the factors that make hospital buildings vulnerable. It discusses the problems of functional vulnerability that could lead to the collapse of hospital service after a sudden-impact event, and to potential damage of facilities, equipment, and non-structural elements.

Chapter 5 deals with how to assess vulnerability conditions. It discusses how to carry out inspections and make inventories of non-structural elements and how to reduce or mitigate risk to hospital buildings, equipment and finishings.

Finally, Chapter 6 addresses professional training in the specific area of architectural design of hospital facilities. It suggests curriculum adaptations and continuing education courses to promote these nontraditional features in the training of architectural designers and builders.

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.

Following is a list of natural phenomena that can cause disasters or calamities:

- Earthquakes
- Tsunamis (tidal waves)
- Volcanic eruptions
- Hurricanes (storms, gales)
- Floods (slow, rapid)
- Massive land movements (landslides, collapses, mudflows)
- 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. Other phenomena that may be considered equivalents include 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 or 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 (*1*). 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 going 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), understood as the probability that an event will occur with an intensity greater or equal to (*i*) during exposure period (*t*) is known, and once vulnerability (V_e), understood as the intrinsic predisposition of an exposed element (*e*) to be affected by or to suffer a loss should a disaster occur with an intensity (*i*), is known, 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 (*2*).

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 (*3*).

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 land 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 (*4,5*).

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 (*6*).

Table 1 shows a list of hospitals that have suffered very serious damage or structural collapse as a consequence of earthquakes.

HOSPITAL	COUNTRY	EARTHQUAKE
Kern Hospital	U.S.A.	Kern County, 1952
Hospital Traumatológico	Chile	Chile, 1960
Hospital 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. SELECTED HOSPITALS DAMAGED BY EARTHQUAKES IN THE REGION OF THE AMERICAS

CHAPTER 2

ARCHITECTURAL DESIGN OF HOSPITALS

CHARACTERISTICS OF HOSPITAL DESIGN

The architectural design of health facilities is a difficult task in which the architect must deal with a very broad range of questions that cover, in addition to the construction of the building, other aspects related to the characteristics of the potential user community, such as the birth rate, morbidity and mortality rates, and micro and macro socioeconomic and geographical considerations. The long and varied list of factors that must be taken into account in order for design to be efficient and effective also includes the advances of medical science and its continuing specialization; the development of new technologies for diagnosis, treatment, and administration; and the complexity of the mechanical equipment and facilities.

Another factor that is becoming increasingly important among the parameters and standards that govern the design of health facilities is the reduction or mitigation of risks from natural or manmade disasters. This is a consideration that must be emphasized in view of the need to ensure the safety of both the health facilities and the community members who use them.

What are the characteristics of a building designed for a hospital facility? It is a complex building which incorporates high-level technology to fulfill a variety of functions, including those of office, hotel, industry, place of worship, and warehouse. This building must also provide for services related specifically to health that require specialized areas with synchronized design, since the lives of patients and users in the building depend on their proper functioning. For these reasons elements must be included in the architectural design to reduce the effects produced by natural phenomena, such as earthquakes, volcanic eruptions, hurricanes, and floods, or phenomena of manmade origin, such as fire, explosion, and contamination, since it is of vital importance to maintain the hospital in operation at all times.

Planning

There are many types of studies involved in hospital design, each of which needs to be explained at length. One of the most important elements in reducing risk and preventing future disasters is the location of the hospital. The location should be based not only on health planning studies from the urban perspective but also on technical evaluations that define land use so as to prevent the siting of hospitals in areas prone to natural hazards and reduce the possibility of their being affected by events such as floods, landslides, and avalanches, and to ensure that their construction does not lead to the development of human settlements in high-risk areas. So far, in Latin America little has been done in standardization and regulation in this regard, and cities consequently tend to expand toward areas inappropriate for human settlement, which only compounds the risk of disaster.

It is difficult to determine the best location of a building in places subject to hurricanes and earthquakes. However, technical and scientific studies exist on land use and topography as they relate to seismic activity that can provide a basis for decision-making in siting hospitals. Environmental considerations such as the absence of bad odors, dust, industrial waste, noise, and pollution in general should also be taken into account.

There are standards in place with regard to the land on which hospital facilities are to be built. So far, however, the standards do not include such elements as spaces for heliports, areas for large-scale care of the injured and treatment of patients poisoned by hazardous materials, and areas for classification or triage in the event of emergency, all provided with open-air sources of water supply and electric power. These considerations require collaboration between the health authorities responsible for issuing standards and the advisory teams that evaluate the areas for hospital construction. Such analysis may determine changes to be made in the use of certain exterior areas in the event that a large disaster strikes. This will be dealt with later in greater detail in discussing the functionality of the building.

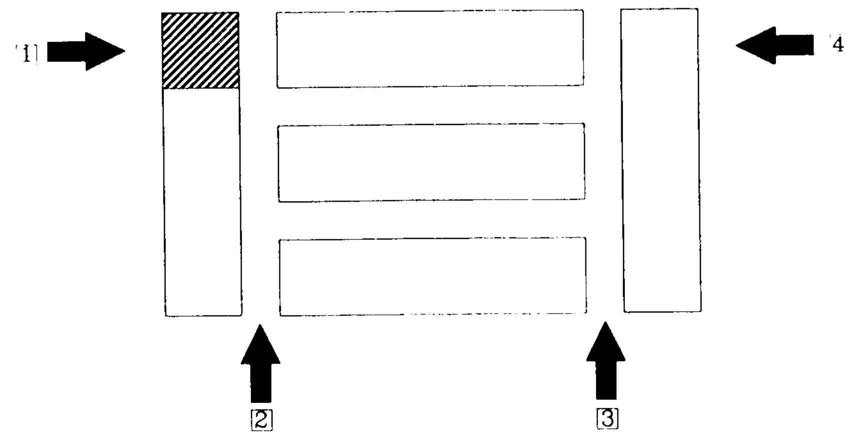
The standards also refer to access to the land occupied by the hospital. Some, for example, indicate that "it should be located on a route of easy and rapid access that is interconnected with the region," but do not provide for the possibility, in disaster situations, of using secondary routes for receiving or evacuating patients when the main routes are cut off. Nor do the standards warn against selecting a hospital site where access to and from developed areas depends on bridges or complex elevated roadways.

Other factors considered by the standards in a rather superficial manner are water, electricity, and sewerage services, and as of a very short time ago, the provision of gas. It is obvious that in the event of an earthquake, water supply is one of the most vulnerable points of a building, and equally so in times of intense summer heat or drought. In addition to providing for a normal supply of water, standards should ensure that the hospital is self-sufficient in this regard for a reasonable amount of time to cover disaster situations. Water supply pipes should be designed so that they provide sufficient flexibility to resist the deformations caused by seismic movement and will ensure continued functioning in the event of fire or other similar disasters.

Much the same can be said about the supply of electric power. Standards indicate that the site selected should be provided with electric power and that there should be an emergency plant capable of covering 50% of the building's consumption in order to supply the priority areas. So far, however, the location of such plants has not been taken into account as a fundamental element in preventing accidents or in guaranteeing their operation in the event of disaster. Considering the design of special conduits to ensure the provision of electric power and maximum safety is of major importance in the planning phase.

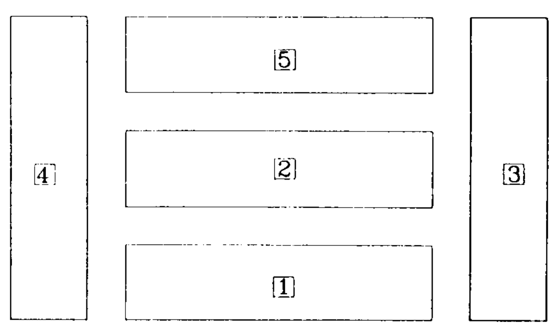
Before referring to the architectural design of the hospital building it is necessary to refer to access to the building per se (Figure 1). Although not usually included in the standards, it is important to define four types of access for a hospital, each with its own characteristics, as follows: one toward the outpatient area, a second toward the administrative area, a third toward the emergency care area, and a fourth for the arrival of supplies and inputs for the general services. The first two are located in external areas for the public, outpatients, and visitors,

FIGURE 1. ACCESS



1. Emergency Care
2. Outpatient Consultation
3. Administration - Visitors
4. General Services

FIGURE 2. ZONING



1. Administration
2. Intermediate Services
3. General Services
4. Outpatient Consultation and Emergency Care
5. In-patient Area

and the other two are in private areas closely related to internal circulation. What might occur regarding hospital access during a disaster will be expanded on in Chapter 3.

Internal considerations and basic areas

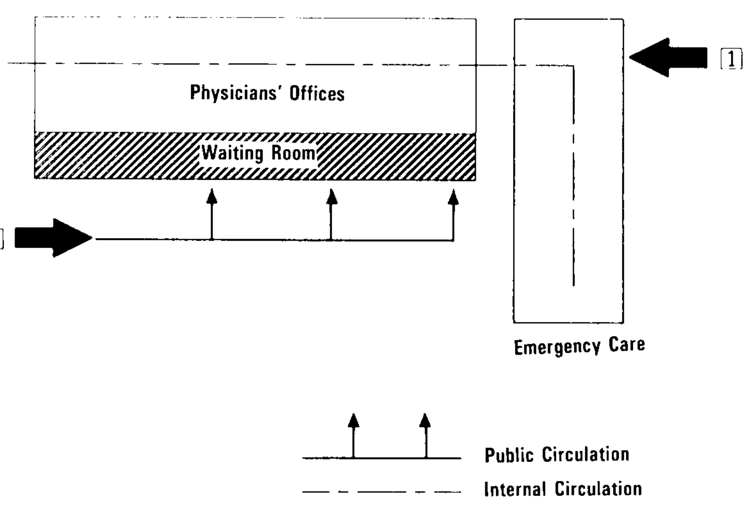
Once the accesses to the building have been defined, a brief description is needed of the areas into which a hospital is divided and of the possible interrelationships between its various services (Figure 2).

A hospital building is made up of five basic areas with very clear-cut and specific functions, which, in turn, must maintain vital interrelationships with one another for smooth operation. These areas are:

Administration, Intermediate or Ambulatory Services, General Services, Outpatient Consultation and Emergency Care, and Inpatient Care (7). These areas are complemented with the very important exterior area, which, as previously mentioned, plays a particularly significant role in dealing with disasters.

Outpatient consultation: This is the area that receives outpatients or ambulatory patients for treatment or diagnosis of their ailments (Figure 3). In addition to medical consultations, this sector includes dentistry, injection and vaccination service, waiting rooms, etc. Emergency Care, with separate access, is included within this area and should be connected by means of an internal passageway. It is important to note that 90% of the patients circulate in this area, and consequently it would be wise to propose that the waiting-room areas in Outpatient Consultation be connected with Emergency Care so that they can be used for patient care in disaster situations, if required.

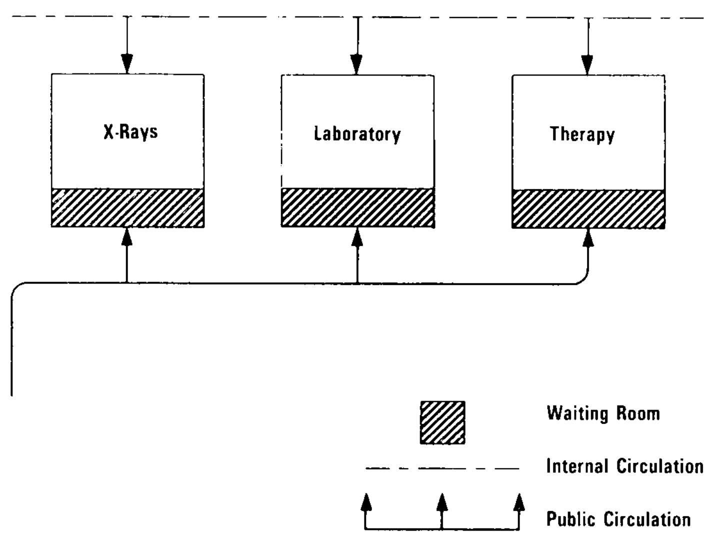
FIGURE 3. OUTPATIENT CONSULTATION



The many standards that regulate this sector have to do with size, function, and use, but none exist that provide for possible change of use in disaster situations. There are also many standards regarding specifications for finishes, but all are oriented toward asepsis, durability, and presentation, and none specify in any way what might be done to mitigate disasters. For this reason, special emphasis will be given to how mitigating elements could be included in standards by changing uses and the specifications of construction, distribution, and function. Change in the use of certain areas with specific functions could result in better use of hospital buildings in emergency situations.

Intermediate services: This area is also known as Diagnostic and Treatment Services. It is composed of the areas that provide X-ray, laboratory, and physiotherapeutic services, whose capacity is directly related to the size of the hospital (Figure 4). Since the Surgery and Obstetrics Unit also provides diagnostic and treatment services, it is located in areas close to the aforementioned areas.

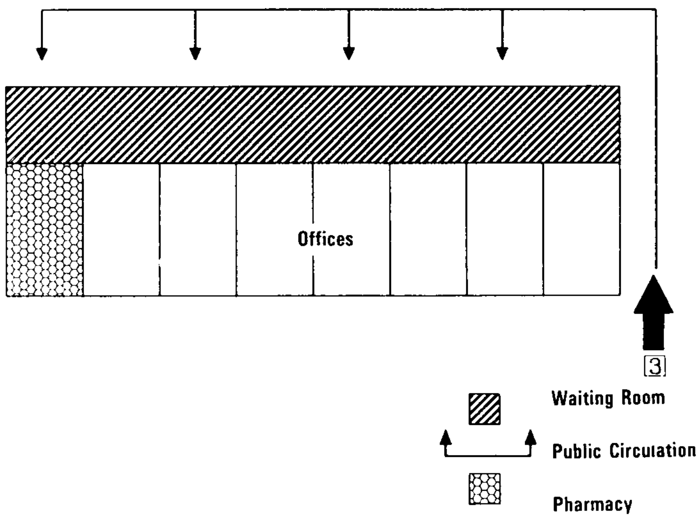
FIGURE 4. INTERMEDIATE SERVICES



It is important for the intermediate services to be directly connected to the external and internal circulation of the surgery area. There are very specialized standards for each of the spaces making up this area, and the areas of surgery and obstetrics are perhaps the most complex. Nevertheless, detailed standards for this area in terms of disaster mitigation have not been considered, and it would be useful to analyze matters such as the location of the Surgery Unit, which in most cases occupies the floors above the basic platform. This Unit could be located on the first floor, with direct internal communication to Emergency Care and a possible connection to the exterior in order to habilitate areas outside the hospital that could, if required, serve as a hospitalization area.

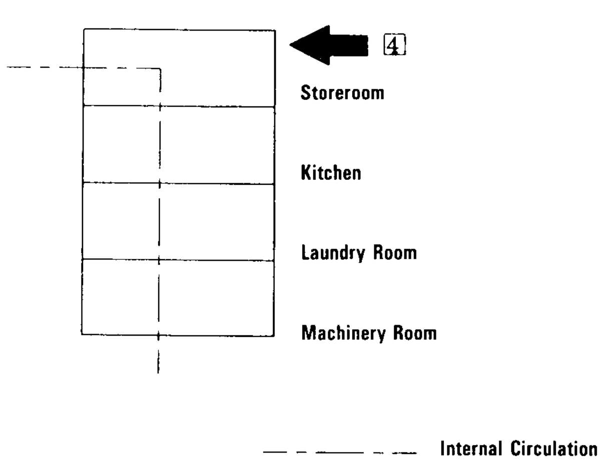
Administration: As its name indicates, this area manages scientific, financial, and organizational functions of the building (Figure 5). Its areas include the executive offices, accounting, management, etc. Also included are sectors that if located in strategic points could be used in the event of disaster. These include meeting and conference rooms, cafeterias, libraries, etc.

FIGURE 5. ADMINISTRATION



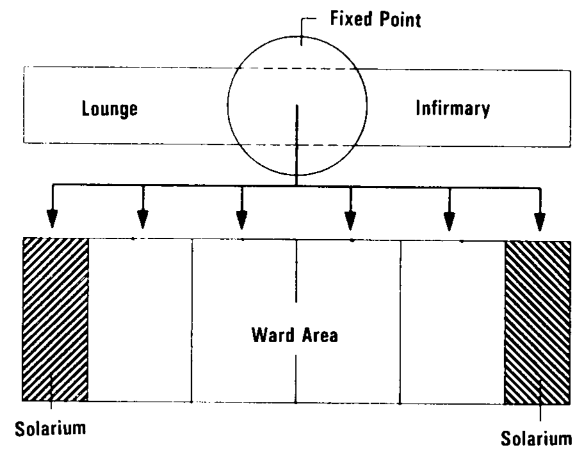
General services: This area includes the laundry, kitchen, storerooms, workshops, plants, boilers, etc. (Figure 6). So far, many mistakes have been made in planning this sector. Since the presence of boilers, fuels, gases, etc., which can become continuous time bombs, threaten the stability of the building, access to this area, as noted above, should be independent and direct from outside, and it should be related to the building by internal circulation.

FIGURE 6. GENERAL SERVICES



In-patient Care: This area may be defined as the hotel area of the building. Although standards exist that prescribe its size, operation, and complementary floor services, very little so far has been written on evacuation of this area in the event of fire or what should be done in the event of an earthquake (Figure 7).

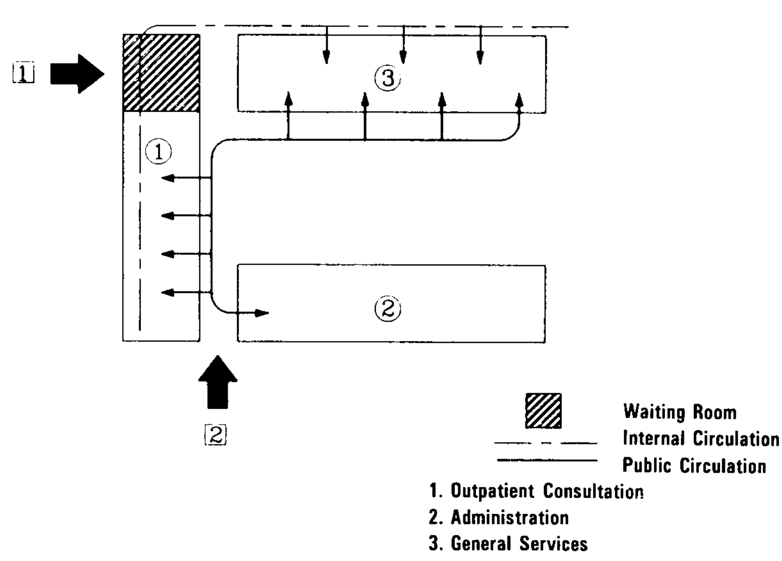
FIGURE 7. IN-PATIENT CARE



INTERRELATIONSHIP OF THE SECTORS

The explanation provided in the preceding paragraphs gives a general idea of each of the areas of the hospital. A brief description is given below of how the five aforementioned areas are interlinked (see Figures 8, 9, and 10).

FIGURE 8. OUTPATIENT CONSULTATION INTERRELATIONSHIPS

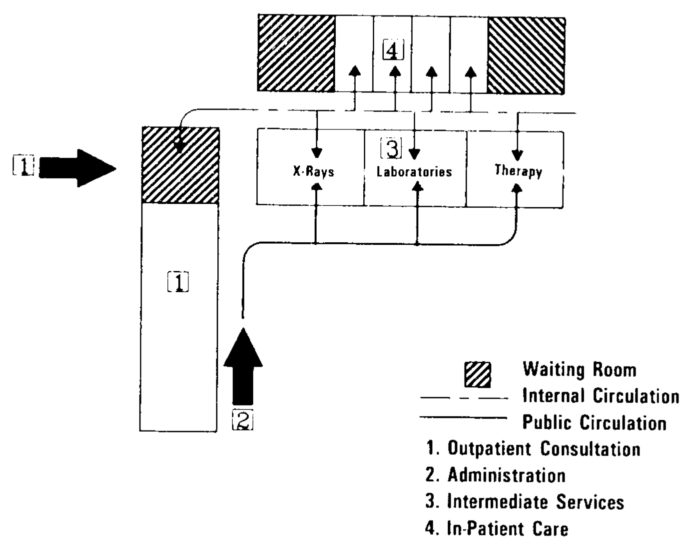


Outpatient consultation: This area has a direct relationship with the intermediate services and the administration, in the first two with internal and external circulation, and with the second, solely with external circulation.

Intermediate services: This area is connected by internal circulation with the area of hospitalization and outpatient consultation, particularly with emergency care and, through external circulation, with the public waiting area.

Administration: Since it constitutes the very core of the overall organization, this area has a direct or indirect relationship with both external and internal circulation, and especially with General Services. It should consequently be located adjacent to these services and have maximum visibility of the unloading area.

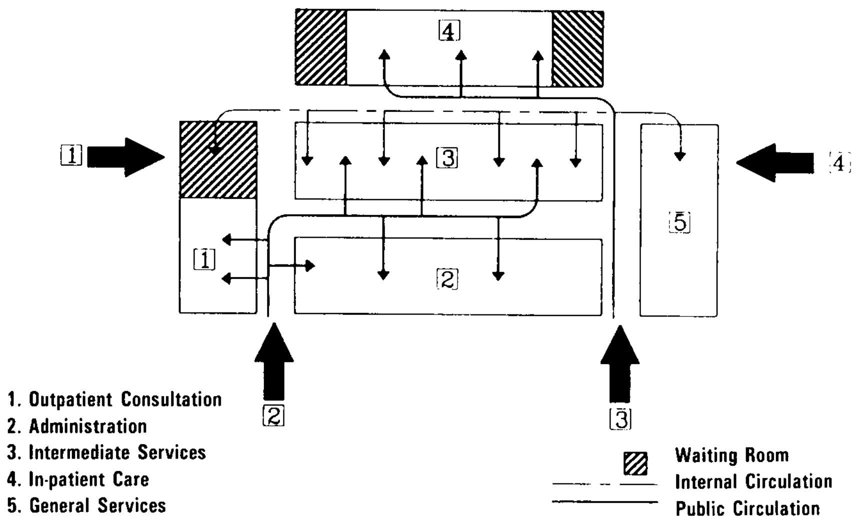
FIGURE 9. INTERMEDIATE AND HOSPITAL SERVICES INTERRELATIONSHIPS



General Services: This area is mainly connected with the hospitalization area by internal circulation and with the rest of the building, since it contains the laundry, kitchen, supply areas, etc.

In-patient Care: This area has an immediate relationship with internal circulation and also with external circulation during visiting hours.

FIGURE 10. GENERAL SERVICES INTERRELATIONSHIPS



CHAPTER 3

MITIGATION MEASURES IN HOSPITAL DESIGN

FUNCTIONAL ANALYSIS OF HOSPITAL SECTORS

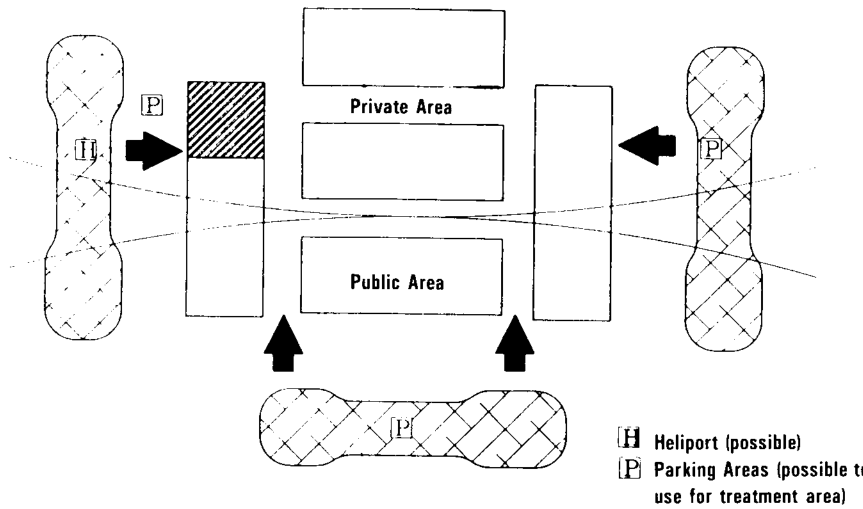
For the analysis of hospital design from the functional standpoint, it is necessary to refer to external aspects relating to site selection, the size of the site, public services, environmental restrictions, and adjacent roadways and their connection with the urban network. It is also necessary to deal with general zoning, that is, with private and public interrelationships, primary and secondary circulation, and the general and private accesses to the basic areas into which a hospital is subdivided. Finally, private zoning must be considered, that is, the internal operation of each of the five aforementioned sectors.

Mitigation measures in hospital planning

As noted in the previous chapter, in the design of hospitals the standards that regulate selection of the site for construction refer specifically to the following:

Dimensions of the site: The area a hospital is to occupy calculated in accordance with the number of beds and the hospital's degree of complexity. It should be possible for the hospital to occupy 50% of the site, with the remaining space as free area for isolation, gardens and parking (Figure 11). The free area should provide the possibility of

FIGURE 11. USE OF FREE AREAS



locating a heliport near the access to emergency services. This heliport should be planned jointly with responsible authorities who can issue guidelines and standards for its location, size, signal equipment, area of influence, etc. Access from the heliport to the emergency service should be free from any obstacle or architectural barrier that could prevent the arrival of stretchers, medical equipment, gas supplies, etc., in emergency situations. The specifications for roadways from the building up to the heliport should comply with standards for weather-resistant finishes and slip-proof, durable surfaces easily identifiable in daytime or nighttime, etc., so as to ensure safe and easy access. It is considered that once these requirements have been met, the standard will be further enhanced, thereby constituting an advance in achieving adequate delivery of hospital services in disaster situations.

Parking areas: With reference to parking areas, the standards simply refer to solving problems regarding the flow and parking of vehicles. However, certain indications with regard to their location and the services required in these areas could convert parking areas into a vital component in dealing with disasters.

For example, the standards could include the following: In addition to specifying the number of parking spaces per bed, a percentage of this area could be located adjacent to the emergency treatment area, since this sector can be habilitated as an area for prehospitalization care. The parking area could be used for the classification of the injured or for triage if massive care of the injured is required, thereby preventing congestion of the hospital (*21*). This area should be provided with special electrical outlets for outdoor use thus making it possible to connect the medical equipment needed during times of large-scale disaster. In addition, this area should be provided with a water supply in order to serve large numbers of burned and poisoned patients.

All these elements could be fine tuned as the concepts presented above are made more explicit, gain greater acceptance, and are subjected to multidisciplinary, in-depth analysis that will provide guidelines as to size, quantity, volume, etc. With reference to the free areas it should also be noted that, if required, they could be occupied by mobile hospitals, thus expanding the possibilities for patient care. Consequently, in addition to water and electric power services, it would be necessary to consider the possibility of gas supply, kitchen services, medicines, etc.

It is important to delimit and pinpoint the parking area for ambulances together with their arrival and evacuation routes, since the organization of the hospital when it is operating normally depends to a great extent on this function, and even more so in a time of crisis that demands large-scale care of the injured.

Furthermore, a number of other important questions should be considered for implementing measures to mitigate risks, such as green areas, the location and type of trees, and footpaths, which should be treated creatively for the purpose of supplementing the standards already in place.

The foregoing considerations lead to a concept of the hospital as a dynamic service and not as a paralyzed building that should be evacuated and forgotten in the event of a disaster, a situation that demands the capacity to support and respond appropriately to such an event and which, in turn, is founded on the compatibility of the structural solution and the architectural solution, and will be discussed further on (see Annex 1).

Public services: In the selection of a site for a hospital the standards specify that it should be provided with public services, that is, water supply and electric power. It is well known that the vital lines or infrastructure of services constitute one of the most vulnerable elements in disaster situations, which include water supply systems, sewerage systems, energy networks, communications, and gas networks. Accordingly, more attention should be paid to public services in order to ensure that the services provided by the hospital can continue after the occurrence of a major disaster.

Energy supply

In addition to public electric power there is a need for providing the hospital with an emergency plant of sufficient capacity to serve at least 70% of the building's normal consumption. Fifty percent, as indicated by the standards, may be insufficient, particularly if it is considered that the standard dates from a time in which the current technology did not exist.

However, the foregoing refers to the capacity of the backup plant; but it is important to ask how should energy supply be handled, how the networks should be designed, and what recommendations can be made to insure that this essential service does not fail in the event of disaster.

Bearing in mind that the electrical system is one of the most vulnerable services in disaster situations, a measure that could reduce the risk of losing this service would be locating the machine room, the substation, and the emergency plants in a structure separate from the hospital building and carefully designed structurally so as to avoid partial or total interruption of this service in the event of an earthquake. These services are important not only for the hospital areas, but also, in the event that a disaster affects the principal buildings, for serving the free areas adjacent to the hospital where mobile hospitals and triage areas could be located.

Cable conduits should be very well planned and located in such a way that it is easy to make inspections, provide maintenance, and effect changes, thereby preventing possible complications and short circuits that could produce fatal situations within the building.

Since the conduits for electrical networks are extremely vulnerable, wiring systems should be designed in such a way as to provide sufficient flexibility to safeguard against breakage in the event of earthquake.

Water supply

As mentioned previously, water supply is an element deserving of special attention in that it is vital in all areas. The standards indicate that a given number of cubic meters of water should be provided per bed, a specification that varies from one place to another. Depending on the location of the hospital, water could in some cases be provided by means of reserve cisterns for periods of drought, which could be fed by deep wells after the water is treated for purity. It is desirable in locating such a supply system to bear in mind the recommendation made for an independent structure, as in the case of the electric power system. The conduit system should also be specially designed so as to provide flexibility in order to survive and continue to provide service after an intense seismic event.

In many cases, the regulations for hospital buildings do not make any reference to the discharge of wastewater. Such waters are in most cases emptied into sewerage systems, rivers, or streams without any prior treatment, consequently affecting the environment and putting the community at risk of infection and mass contamination, which in turn could create other kinds of disaster situations. Treatment systems should be planned for in existing and future buildings to avoid discharging untreated wastewater into urban collection systems.

Gas supply

One of the services that deserves special attention is the network for supplying gas for domestic use. In some countries of the Region this kind of service was initiated only a short time ago, and consequently the time is ripe for incorporating special specifications for the design and construction of these kinds of networks in order to reduce the possibility of emergency situations, particularly after earthquakes. Shut-off valves that operate automatically in response to vibration and changes of pressure are recommended not only on urban lines but also in important buildings such as hospitals.

It is very important to evaluate the application of new technologies such as solar energy heating systems, which can reduce emergency situations produced by boilers and can lessen the high operating costs that will, over time, impinge upon the financial situations of hospitals.

Environmental restrictions

Building standards usually suggest that flat land should be selected for hospital sites, which is problematical for countries whose cities are primarily situated in mountainous areas. Nevertheless, the most important consideration to take into account in site selection for the future hospital is that the site not be located in areas that are unstable or prone to slippage. On several occasions hospitals already constructed or under construction were subsequently affected by instability, thereby necessitating large-scale investment to resolve these problems.

Health-sector buildings located near industries that can cause contamination or even explosions and fires are also at risk. In the event the site is located near a river or a stream, it is necessary to determine the possibilities of flooding. Relocating the project, if required, should be considered, or an architectural solution should be found for the problem.

Road network

The standards specify that a site for a hospital, depending on its level of complexity, should be located near a major roadway that connects developing areas of the city and, in some cases, other municipalities. As mentioned before, this must also be taken into account in dealing with risk factors in general, since saving many lives in the event of disasters resulting from earthquakes, fires, and floods depends on good communication with urban centers.

The foregoing considerations lead to the conclusion that it is essential to locate hospitals not only adjacent to one important roadway, but perhaps to two or three, which will make it possible to have alternate routes for the arrival or evacuation of patients. Roadways should be built to accommodate these requirements and plans must be prepared with the responsible authorities for evacuating the area, indicating which actions should be carried out to ensure that traffic is not interrupted. This will make it possible to establish access and evacuation routes clearly, together with their various possibilities, depending on the affected areas in the event of a disaster.

As noted previously, it is not desirable to locate a hospital on either side of a single roadway connected by a bridge. If the bridge were affected by a flood or an earthquake, the hospital would be isolated.

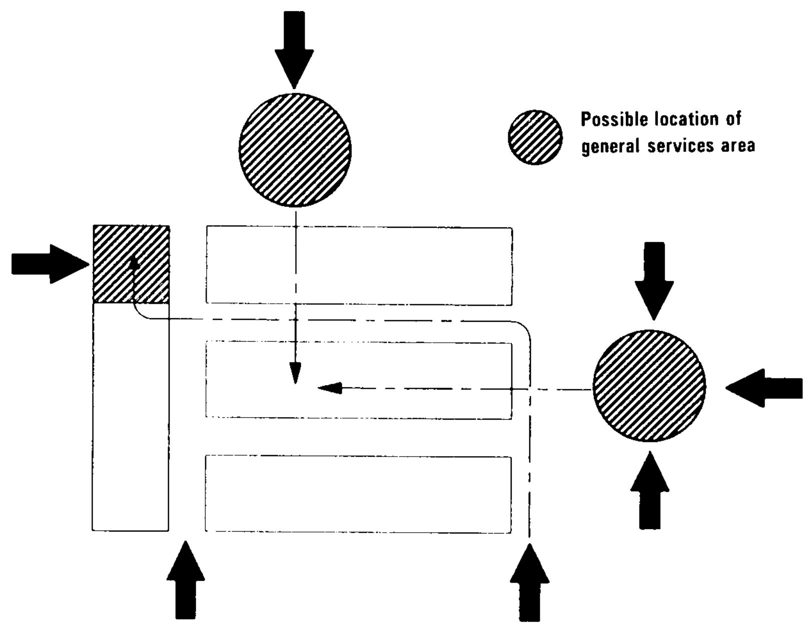
As has been illustrated, access to a hospital is a critical consideration that must be taken into account, not only with respect to future designs, but also in the case of existing buildings, since although the services may not be affected directly by a disaster, difficult access could interrupt operation of the hospital and prevent its functioning when it is most needed.

Mitigation measures in general zoning

The preceding chapter indicated the areas making up a hospital and also referred to the need for making certain design variations that would help to mitigate disasters in the building (Figure 12).

It is considered essential, not only for the purpose of disaster mitigation and prevention but also for the administration of the building, that the possibility be explored of separating the General Services sector

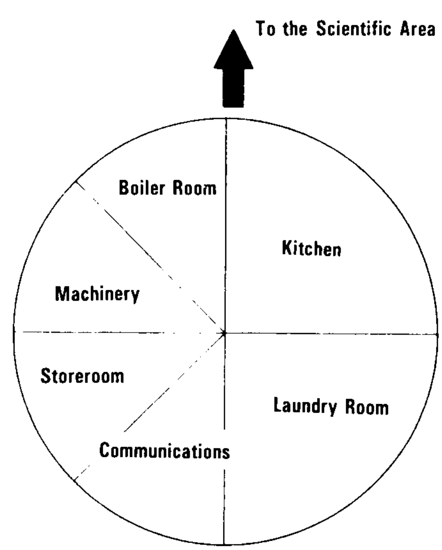
FIGURE 12. LOCATION OF GENERAL SERVICES



from the main block of the hospital building (Figure 13). Following are reasons for taking this architectural design measure:

a. The boiler area is usually located in the General Services sector, which in most cases becomes a dangerous time bomb that can produce untold disaster if an explosion occurs.

FIGURE 13. DISTRIBUTION OF GENERAL SERVICES



If the boilers are located outside of the main building, the damages to the general infrastructure would be mild in the event of an explosion and would affect the hospital's operation to a lesser degree. This is also the case of the hospital's gas plant. Although it is true that building a separate structure for these services would increase the initial costs of construction, the increase would be of little consequence compared with the cost of the damages ensuing from an explosion.

b. Another service that is commonly located in the General Services sector is the emergency plant. This service could also be located separately, not so much because of the inherent risks it involves as for the advantage offered by its possible use during critical moments.

   If located outside the main building, this plant, in the event of fire or earthquake, could be used to carry out many activities, either outdoors or in sectors of the building that have not been affected. Since the substation and the control panels are located together with the emergency generator, this entire energy complex would be located in the proposed independent structure, whose seismic-resistance specifications would be much stricter in order to ensure its operation even in the event of an intense earthquake.

c. For the same reasons it is considered desirable to locate telephone, radiocommunications, and similar services in this sector, since as in the case of the energy system, they may be used in the event of a disaster situation.

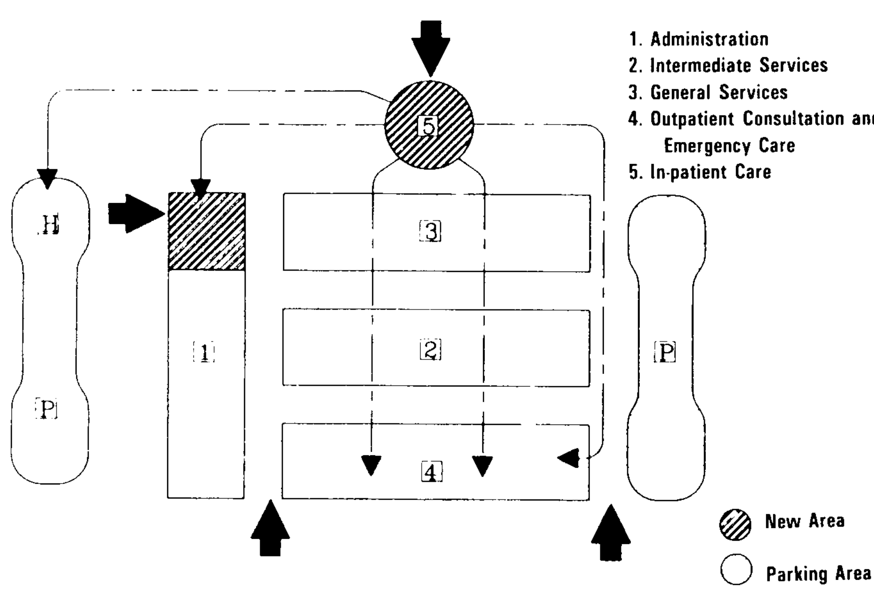
   As mentioned previously, it also is desirable, whenever possible, to locate hospital water storage tanks in this area. Since they are most commonly located on the upper floors of the building, they represent additional loading on the structure and thus increased risk. If these services are located in the independent structure proposed for the general services sector, they would not only reduce the lateral loads on the main building in the event of earthquake, but also make it possible to ensure permanent and continuous water supply during the postdisaster period. With a guaranteed electric power supply, water-pumping equipment would remain in operation, thereby making it possible to supply the building and the fire-fighting system, constituting one more element for the mitigation and prevention of disasters.

d. It would also be desirable to locate the kitchen services within the proposed independent structure, where they would be provided with water, electric power, and gas services. Food supply could be available not only for the usable sectors of the hospital building but also for the adapted areas in the open areas. Something similar would occur with the laundry service, which would complete the package of facilities available to serve either partially or totally the areas of the hospital affected by the event or a possible field hospital.

It should be noted that the foregoing is possible if an entire multidisciplinary team is available in which engineers, architects, and planners, as well as medical and paramedical personnel, participate in making general proposals for actions, responsibilities, movements, and physical solutions to implement the above recommendation.

This new area or sector of the hospital may be likened to a kind of bunker that houses vital equipment--similar to an intensive care unit--that would be designed to supply and control communications and water, gas, and electrical power to serve either partial or full operation of the hospital or even, in an extreme case, a field hospital (Figure 14).

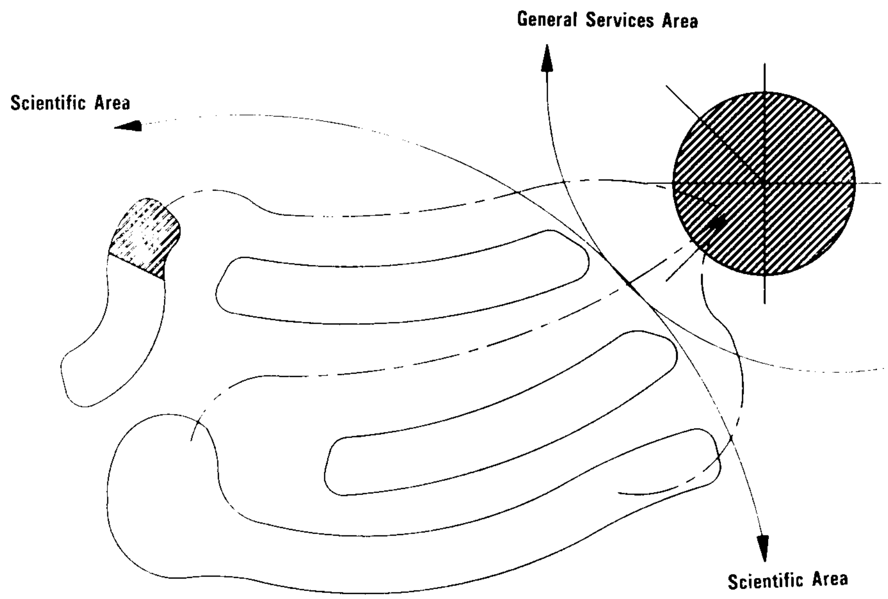
FIGURE 14. NEW GENERAL SERVICES AREA



Mitigation measures in specific zoning

One mitigation measure in general zoning that has been proposed is the possibility of a new location of the general services, which would involve having two buildings with very distinct characteristics--one, referred to in the section above, would be controlled from the administration, and the other would be the scientific area, to which reference will be made below (Figure 15).

FIGURE 15. RELATIONSHIP OF SCIENTIFIC AND GENERAL SERVICES AREAS

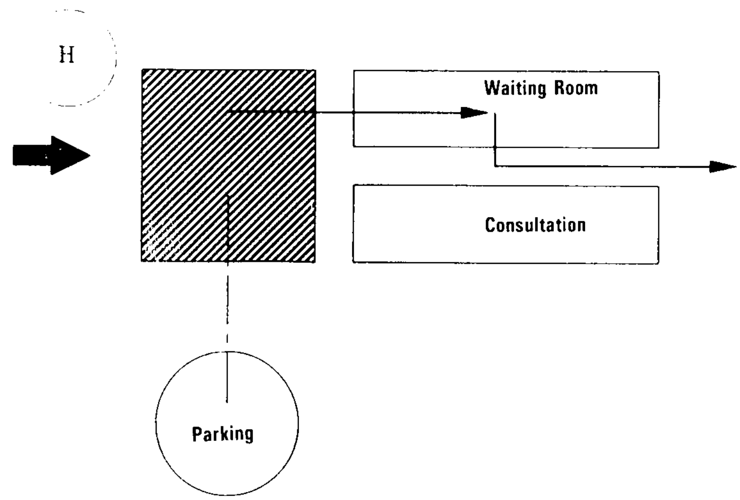


The scientific area would include the four remaining sectors of the hospital: Outpatient Consultation, Intermediate Services, In-Patient Care, and Administration. As previously mentioned, the outpatient consultation area includes the emergency room, considered as a vital area for serving patients in case of emergency.

In normal situations, the emergency care area deals with 10% of the patients who arrive in the outpatient care section, while the remaining 90% are served by Outpatient Consultation. In disaster situations, depending on their magnitude, the proportion is totally reversed, which immediately suggests that it would be wise to think about a solution--that is, what adjustments should be made to the functions of Outpatient Consultation so that when an emergency occurs this sector will be in a position to support the response of the hospital (*9*).

The standards specify that Emergency Care should be connected by internal circulation to the area housing the physician's offices in which the movement of medical and paramedical personnel will take place (Figure 16). It is also specified that the sector should be divided into a white area and a red area, and the standards also prescribe norms for each of these spaces with regard to finishes, size, equipment, and the like. It is also important to note that the emergency care area should be located in such a manner that its internal circulation is connected to the outpatient consultation waiting room area so that in disaster situations it

FIGURE 16. EXTERNAL EXPANSION OF THE EMERGENCY CARE AREA



can be rehabilitated to allow the location of stretchers and additional equipment necessary for the care of patients.

The foregoing leads to the conclusion that the emergency care area may be expanded not only toward the exterior, as previously noted, but also toward interior areas. In the event of a major disaster, Outpatient Consultation in and of itself will not provide this service to the public, which is the reason why it may be temporarily organized to care for those who have been injured by the disaster.

It should also be noted that with regard to technical facilities there is a need for planning the eventuality of linking up portable X-ray, oxygen, resuscitators, and monitoring equipment in order to habilitate the waiting-room area efficiently.

If the physician offices in Outpatient Consultation are designed simply, using finishes that provide aseptic conditions, they may be used in emergency situations for carrying out medical procedures, treatment, and even minor surgery if the conditions so permit.

By taking into account the above observations, the entire Outpatient Consultation sector can be habilitated as a large emergency area in disaster situations if the safety of the building so permits (Figure 17).

If rationally planned, the general entrance or lobby area could be appended to this sector, which would significantly assist in increasing its usability.

A sector considered to be of vital importance for the development of a good emergency service is Diagnosis and Treatment. Depending on the architectural design, solutions may be proposed for this sector similar to those proposed for Outpatient Consultation, that is, the possibility of converting the waiting areas located in the external circulation into areas for patient care (Figure 18). For this reason, in addition to the necessary electrical installations and those commonly used in this area, the possibility should be foreseen of installing special equipment for these kinds of situations, as previously indicated.

FIGURE 17. EXPANSION OF EMERGENCY CARE TOWARD THE ENTRANCE HALL AND CONSULTATION AREA

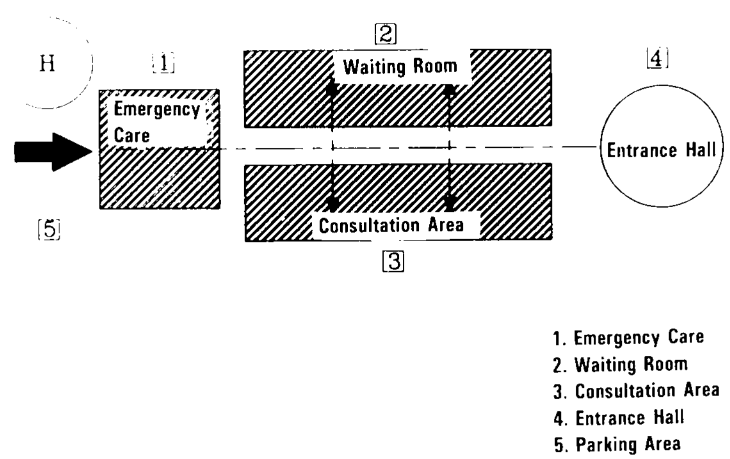
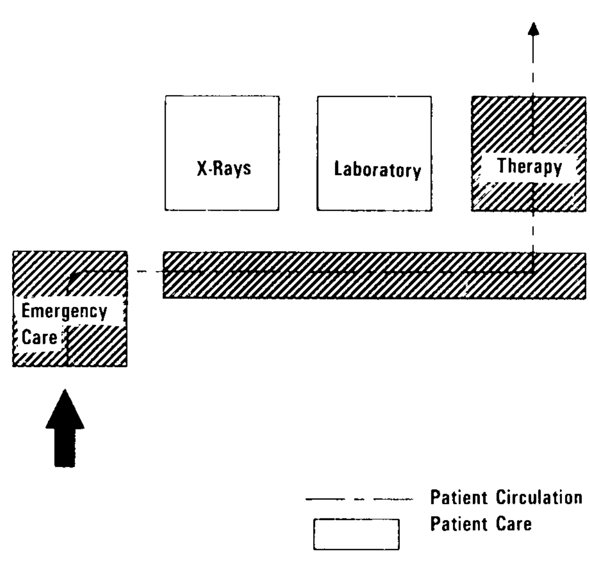


FIGURE 18. EXPANSION OF THE EMERGENCY CARE AREA



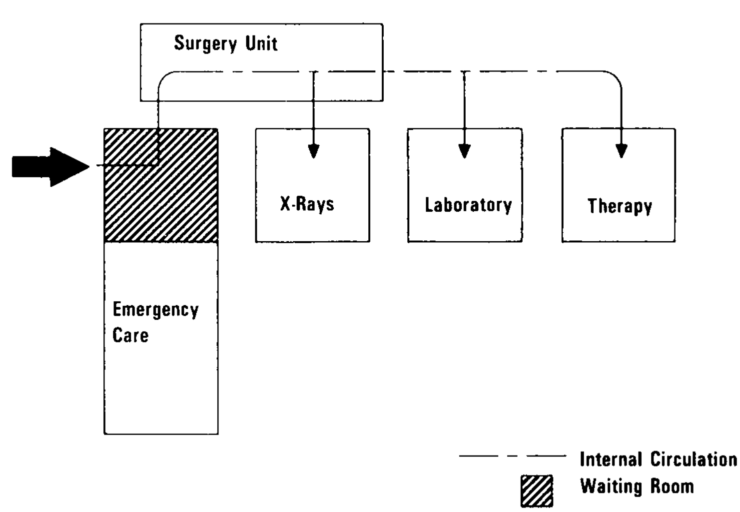
The areas set aside for Physiotherapy, and especially the Exercise Room located in Diagnosis and Treatment, are a vital sector to be used in disaster situations for several reasons, one being their location between internal and external circulation, which makes it possible to convert the sector into a filter toward the areas set aside for radiography, laboratory, and surgery. Another important reason derives from their size, which provides sufficient capacity for their being used as a filter or anteroom for access to the surgery area. A third reason is that in most cases the specifications for finishes in this sector provide good aseptic conditions. It follows, then, that the Physiotherapy area is supremely useful for satisfying new needs at a particular time.

It is also important to attach the Surgery and Obstetrics Unit to this sector, which in most cases is located at levels above the Diagnosis Unit (Figure 19).

A significant recommendation with regard to this sector as far as disaster mitigation is concerned is that the standards should specify that the Surgery Unit in hospital buildings should be located on the lower floors, which are less vulnerable than the upper floors and can consequently provide greater assurance for continuance of this service.

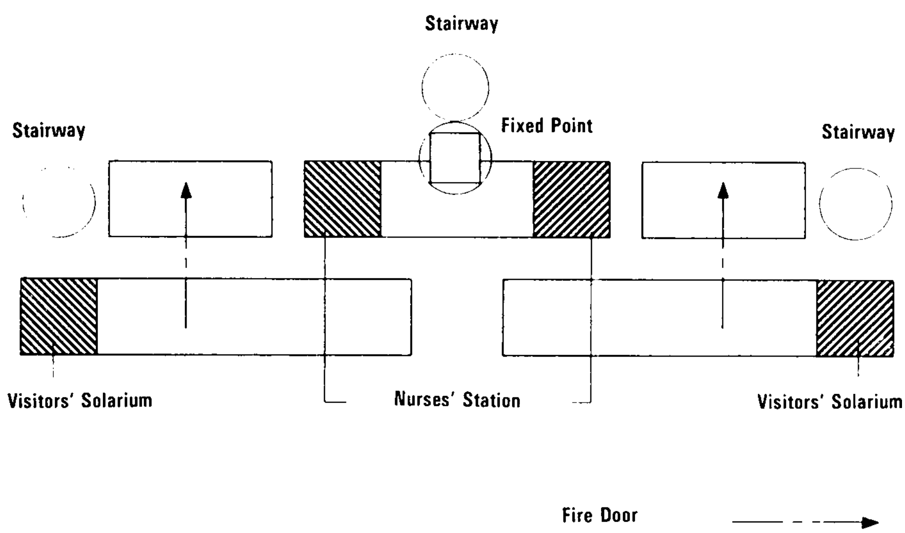
Another important element of architectural planning proposed is proximity of the X-ray, laboratory, and emergency care areas, avoiding vertical movement, and shortening the time of transfer of patients. This is feasible if the General Services area is well planned, since, as previously suggested, if they are located separately, these services would provide the opportunity of functionally relocating not only the surgery services, but also the central sterilization unit, the intensive care unit, and the obstetrics unit.

FIGURE 19. NEW LOCATION OF SURGERY UNIT



As is well known, the inpatient area is one of the sectors that has been most regulated over time, particularly with regard to size, movement, operation, and finishes. However, little or nothing has been regulated with regard to the mitigation of disasters, a matter that is of great importance given that in most cases this service is located on the upper floors of hospital buildings (Figure 20). It is primarily the task of the engineers designing the structure to consider matters concerning the resistance, ductility, and structural behavior that will make it possible to reduce the vulnerability of the building, which is closely related to the conceptions of volume and configuration produced by the architectural designer, as will be discussed further on.

Figure 20. General Distribution



A primary consideration concerns the fire prevention network, which should be maintained and inspected periodically in order to keep it in perfect operating order in disaster situations (*10*). A standard exists for health facilities that indicates that fire stairs should be no more than 35 meters distant from any point and that the materials used for their construction should be fireproof; other specifications exist relative to their width and height, as well as to air injectors. Unfortunately, few of these standards are applied. This standard could additionally recommend that in some cases the stairs not have access to the first floor but only to the ground floor, except in the case of staircases for the public, so that the first floor does not become congested and people can spread out on the ground floor and be evacuated by means of outside or fire stairs.

It is also important to include firedoors in hospital design, which consist of fire-resistant sliding doors installed in the walls to isolate sectors and avoid the spread of fire. This, together with the specifications for materials, are of particular importance in preventing and mitigating disasters in hospitals (*11*).

So far we have addressed architectural changes relating to function and to special situations related to zoning and layout in hospitals as far as disaster prevention is concerned. Hereinafter reference will be made to each of the areas in particular, emphasizing their distribution and possible internal and external changes aimed at converting these sectors into more efficient areas in case of emergency.

In the area of Outpatient Consultation and Emergency Care there is an internal distribution which, with certain changes, could be used to great advantage in mitigating disasters.

The area of Emergency Care is divided into two principal environments, the red area and the white area. The first refers to those areas in which certain procedures are carried out in which blood is involved, such as minor surgery, etc., which is the reason why this area contains such a high proportion of medical equipment and personnel specialized in trauma. It has been proposed that locating it between access from the exterior and its extension toward the outpatient waiting-room area is of great importance in ensuring the relationship of the services in the event of emergency. The role assigned to the white area would be different, since this sector contains the physicians' offices, the water supply works, and observation areas which, although located parallel to the red area, could be used for provisional triage or classification of patients entering the red area, the waiting area, or other areas located adjacent to the exterior.

As previously mentioned, Outpatient Consultation may also be temporarily converted into Emergency Care, not only in the waiting-room areas, but also in physicians' offices, the specialized areas, and the injection and vaccination areas. In most cases Outpatient Consultation is an area near or adjacent to the entrance hall or main lobby, a space that is appropriate for providing medical care on a large scale in disaster situations (Figure 21).

It is important to locate the nurses' station in emergency care areas in order for it to be able to be converted into an area that can function as a center for information, administration, and communications.

Areas devoted to physicians' offices, injection, vaccination, etc., can be utilized for procedures rooms, and injection and vaccination rooms can be used for minor surgery. The Outpatient Consultation, Emergency Care, the adjacent exterior sectors, the waiting areas, and the main lobby area could become a large-scale emergency treatment service efficiently distributed as shown in Figure 22.

As previously mentioned, the area of Diagnosis and Treatment is considered important in a time of disaster, since it can expand the area of emergency care and because it can be converted into a final filter within the operative procedures. Once the routine procedures have been carried out in the sectors in which triage is performed, special

FIGURE 21. GENERAL EMERGENCY CARE AREAS

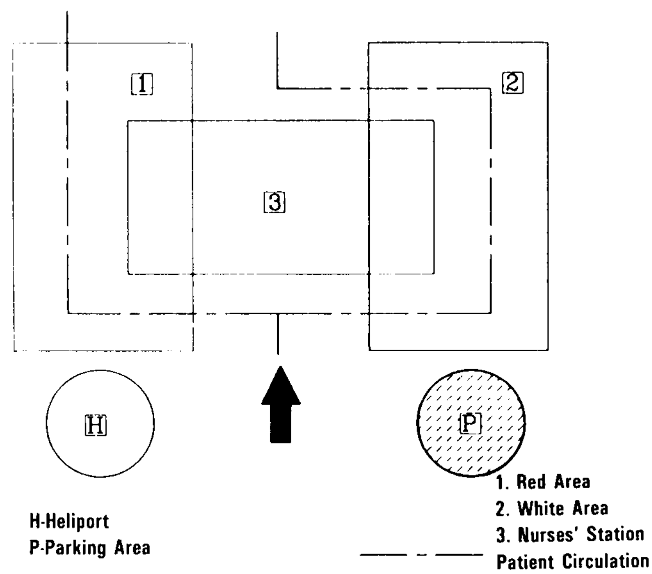
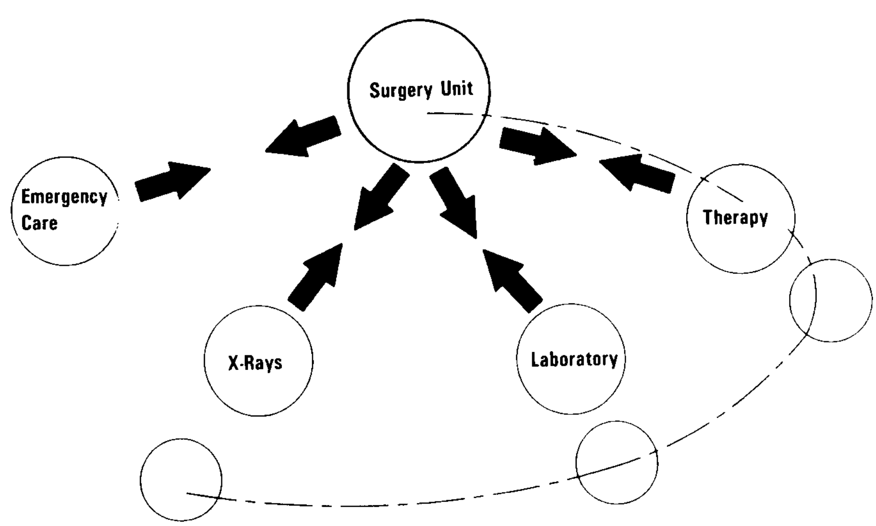


FIGURE 22. LOCATION OF SURGERY UNIT AND INTERMEDIATE SERVICES



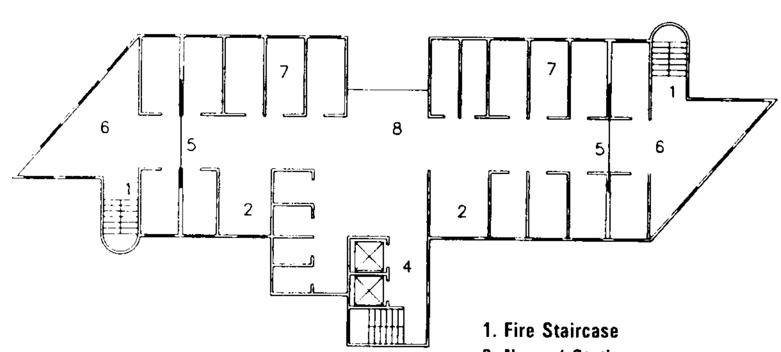
classification can occur in the Exercise Room, which, owing to its characteristics and finishings, can function as an area for preoperation preparation of patients, supplemented by the proximity of the X-ray and laboratory services that are essential prior to operation.

The changes suggested for adapting hospital design to disaster situations would be enhanced if the standards for the distribution of areas were precisely specified and if the Surgery Unit, as a diagnosis and treatment service, were located adjacent to the area of Intermediate Services. This would be possible if the General Services occupied the suggested position outside the main building.

There are very few variations that can be proposed for the Surgery Unit, given the functions it performs. However, it is worth noting that the specifications for electric power networks should satisfy the maximum safety requirements with regard to heights of outlets and conductive floors, and that basic requirements for avoiding explosions from concentration of medicinal gases be followed. In order to maintain internal pressures, air supply and renewal systems should also comply with maximum safety and flexibility conditions so as to absorb the shock of movements in the event of earthquake. The proposed modifications can be carried out as illustrated in Figure 23.

Two areas are distinguished in the inpatient area: the service area and the area served. The first contains the nursing, treatment, consultation, and storeroom services, in addition to bathrooms; and the second, the patients' rooms. Distances are calculated so that the fire stairs are no further than 35 meters away from the nursing station and the firedoors are properly placed.

FIGURE 23. NEW DISTRIBUTION FOR SURGERY UNIT



1. Fire Staircase
2. Nurses' Station
3. Elevators
4. Stairway and Public Hall
5. Fire Door
6. Solarium, Possible Patient Area
7. Expandable Patient Rooms
8. Visitors' Area, Possible Patient Area

PROBLEMS OF FORM AND VOLUME

By their nature hospital structures tend to be large and complex, which means that in many cases their configuration is complex. Configuration, as the term is used here, does not refer solely to the form of the structure in the abstract, but to the close interrelation of the type, layout, fragmentation, resistance, and geometry of the building, an interrelation which gives rise to certain problems of structural response to earthquakes. When planning a hospital, it should be noted that one of the greatest causes of damage to buildings during earthquakes in the past has been due to improper architectural-structural configurations. Generally speaking, it may be said that a departure from simple structural forms and layouts is severely punished by earthquakes. In addition, unfortunately, the usual methods of seismic analysis do not succeed in quantifying most of these problems appropriately. In any case, given the erratic nature of earthquakes, in addition to the possibility that the design level will be exceeded, it is advisable to avoid hazardous configurations, regardless of the degree of sophistication that may be achieved in the analysis of each case (*12*).

A brief discussion follows of the impact of configuration on the seismic response of buildings and of corresponding corrective mechanisms. It should be emphasized that due to their complexity and to their close relationship to the proposed size and shape of the construction, the problems of configuration should be essentially addressed once the spatial layout of the building has been preliminarily defined and throughout the formal and structural design stage (see Figure 24). For this reason this is a subject that architectural designers must fully understand (*13*).

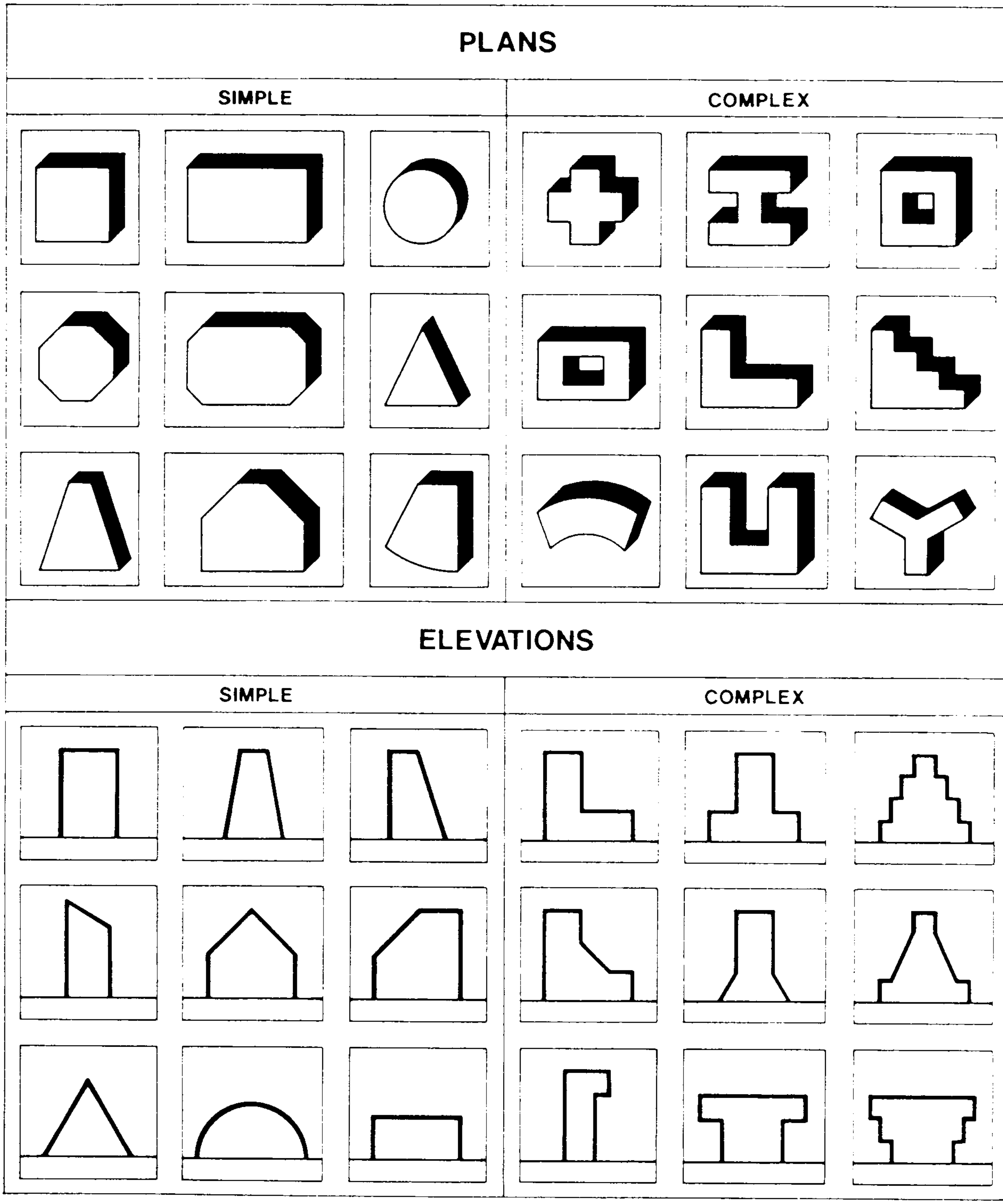
Problems of configuration in the ground plan

The problems referred to below have to do with the horizontal layout of the structure in relation to the form and distribution of the architectural space.

Length

The length of a building determines its structural response in a manner that is not easy to determine by usual methods of analysis. Since ground movement consists of a transmission of waves, which occurs with a velocity that depends on the mass and stiffness of the supporting soil, the excitation that takes place at one point of support of the building at one time differs from the excitation at another time, the difference being greater as the length of the building is greater in the direction of the

FIGURE 24. SIMPLE AND COMPLEX SHAPES IN PLAN AND ELEVATION



From Arnold, Christopher and Reitherman, Robert, *Building Configuration and Seismic Design* (John Wiley & Sons, New York: 1982, p. 232). Reprinted with permission of John Wiley & Sons.

waves. Short buildings adjust more easily to the waves and receive a similar excitation at all supports, unlike long buildings.

Long buildings are also more sensitive to the torsional components of ground movements because the differences in the transverse and longitudinal movements of supporting terrain, on which this rotation depends, are greater.

The usual solution to the problem of excessive building length is to partition the building into blocks by inserting joints in such a way that each of the sections can be considered as short. These joints should be designed to permit adequate movement of each block without danger of pounding, as described further on.

Flexibility

The flexibility of a structure under seismic loads may be defined as its ability to resist large lateral deformations between the floors, known as drifts. The leading causes are the distance between the support elements (clear spaces or clearances), their vertical clearance, and their stiffness. The degree of flexibility can determine:

- Damages to the nonstructural elements attached to contiguous levels.
- Instability of the flexible floor or floors, or of the building in general.

Lack of redundancy

Seismic-resistant design takes into account the possibility of damage to elements during the most intense earthquakes. From this standpoint, the design of the structure should ensure that resistance to seismic forces does not depend largely or totally on a limited number of elements, since their failure could result in partial or total collapse immediately after the earthquake because of the weakness of the remaining elements. The aim should be to distribute the resistance to seismic forces among as many elements as possible (*14*).

The problem of lack of redundancy is usually linked to the problem of flexibility, since fewer elements in a given area implies the presence of large gaps between supports and, accordingly, less lateral stiffness of the structure.

Torsion

Torsion has been the cause of major damage to buildings subjected to strong earthquakes, damage that ranges from the sometimes visible warping of the structure (and its resultant loss of image and reliability) to structural collapse.

Torsion takes place because of the eccentricity of the center of mass in relation to stiffness. The three major situations that can give rise to this situation in plan are:

- The positioning of the stiffest structure asymmetrically with respect to the center of gravity of the floor.
- The placement of large masses asymmetrically with respect to stiffness.
- A combination of the two situations described above.

It should be borne in mind that the dividing walls and the facade walls that are attached to the vertical structure are usually very stiff and, accordingly, as long as their resistance is greater than the stress of the earthquake, they participate in the structural response to such stress and torsion can result, as commonly occurs in corner buildings.

If height is also considered, the situation with respect to torsion may become even more complicated when there are vertical irregularities, such as setbacks. The upper part of the building transmits an eccentric shear to the lower part, which causes downward torsion of the transition level regardless of the structural symmetry or asymmetry of the upper and lower floors.

Quantitatively, eccentricity between mass and rigidity may be considered large when it exceeds 10% of the dimension in the plan under study. In such cases corrective measures should be taken in the structural layout of the building.

As with all problems of configuration, the problem of torsion should be addressed starting in the spatial and formal design stage. The necessary correctives to the problem of torsion may be summarized as follows:

- Torsion should be considered unavoidable because of the nature of the phenomenon and the characteristics of the structure. For this reason, it is suggested that buildings be provided with what is known as "perimetric stiffness" which is aimed at bracing the structure against any possibility of gyration and distributing torsional resistance among several elements in accordance with the need for redundancy.
- In order to control elastic torsion, careful attention should be paid to the layout of the structure in plan and in elevation, in addition to the presence of and need for isolation of the partition wall that could be structurally involved during an earthquake, as will be discussed later

on. The objective at all times should be the greatest possible symmetry between stiffness and mass.

Flexibility of the diaphragm

Flexible behavior of the floor diaphragm implies greater lateral deformations, which are in principle detrimental to the nonstructural elements attached at contiguous levels. Additionally, the assembly work of the vertical structure by the diaphragm is deficient, and consequently there is greater stress on some elements and less on others.

There are several reasons why this type of flexible stress may occur, as follows:

- *Flexibility of the material of the diaphragm.* Among the usual building materials wood presents the greatest disadvantages in this regard.
- *Aspect ratio of the diaphragm.* Since this is a matter of flexural stress, the larger the length/width ratio of the diaphragm or of a segment of it, the greater its lateral deformations may be. In general, diaphragms with aspect ratios greater than 5 may be considered flexible.
- *Rigidity of the vertical structure.* The flexibility of the diaphragm should be also be judged in accordance with the plan distribution of the stiffness of the vertical structure. In the extreme case of a long diaphragm in which all elements are of equal stiffness, better performance of the diaphragm may be expected than when there are major differences in this respect.
- *Openings in the diaphragm.* Large openings in the diaphragm for purposes of illumination, ventilation, and visual connections between floors cause flexible areas to appear within the diaphragm that impede the stiff assembly of the vertical structures.

There are many solutions to the problem of flexibility of the diaphragm, depending on its cause. In principle, for large structures, such as hospitals, building floors with flexible materials such as wood should be avoided. Second, as is the case with the effects of length, buildings with a large plan aspect ratio should be segmented by means of joints. Third, very large differences in stiffness between the elements of the vertical structure should be avoided. Finally, large openings in the diaphragm should be studied carefully in order to provide for stiffening or, if this is not possible, segmentation of the building into blocks should be considered.

Concentration of plan stress

This problem arises in buildings known as complex plans and is very common in hospital buildings. The definition of such a plan is one in which the line joining any two sufficiently distant points of the plan lies largely outside the plan. This occurs when the plan is composed of wings of significant size oriented in different directions (H, U, L shapes, etc.). In them, every wing can be likened to a cantilever built into the remaining body of the building, a site at which it would be subjected to smaller lateral deformations than in the rest of the wing. For this reason large stresses appear in the transition area, where damage frequently occurs to nonstructural elements, to the vertical structure, and even to the diaphragm.

In this case the solution ordinarily adopted is to install seismic separation joints, such as those mentioned in the case of long buildings. These joints enable each block to move on its own without being tied to the rest of the building, thus breaking the pattern of cantilever stress on each wing. The joints must obviously be wide enough to allow the movement of each block without pounding (*15*).

Problems of vertical configuration

Concentrations of mass

The problem in question is caused by high concentrations of the total mass of the building on a given floor because heavy elements, such as equipment, tanks, storerooms, files, etc., have been placed there. The problem worsens the higher the heavy floor is, since the seismic response accelerations also increase upward and there is consequently a greater seismic response force at that point and a greater possibility of collapse.

The architectural design of these buildings should place whatever areas involve unusual weights in basements or in separate structures near the main body of the building. In cases in which for topographical reasons large amounts of water must be stored at high elevations, independent towers should be selected for this purpose instead of towers attached to the main building.

Weak columns

The seismic design of frames aims at ensuring that the damage produced by strong earthquakes occurs to beams, not columns, since there is a greater risk of building collapse from the latter type of damage. However, many buildings designed according to seismic resistance codes have failed for this reason. These failures can be grouped into two categories:

- Columns with less resistance than beams
- Short columns

There are several reasons why the value of free length is reduced drastically and the result can be considered a short column:

- Partial lateral confinement of the column by dividing walls, facade walls, retaining walls, etc.
- Placement of slabs at intermediate levels
- Location of the building on a slope

Short columns are the cause of serious failures in buildings subjected to seismic excitation, since their failure mechanism is fragile. The most appropriate solutions in the case of all kinds of wall that impede the free movement of the column consist basically of placing the wall in a different plane from that of the column, or in separating the wall from the column by means of joints. In the case of buildings with intermediate levels, the architectural design should consider locating the columns outside the transition line between the levels. Finally, on sloping land, the foundations of the columns ought to be sunk at greater depths.

"Soft" stories

Several types of architectural and structural plans lead to the formation of so-called "soft" stories, that is, stories that are more vulnerable to seismic damage than others, since they have less stiffness, less resistance, or both. The usual plans are:

- A story that is significantly taller than others
- Interruption of vertical structural elements on the floor
- Construction on a slope

The first case frequently arises because of a desire to place greater masses at certain levels of the structure, usually for technical reasons (equipment requirements, etc.) or aesthetic reasons (the building's appearance at the access levels, etc.). As a result, stiffness on the floors in question weakens due to the higher elevation of the vertical elements and of the resistance.

The interruption of vertical elements of the structure has proven to be the cause of multiple partial or total collapses in buildings subjected to earthquakes. The reason is that the floor on which the elements are interrupted has greater flexibility than the others, thus aggravating the problem of stability; in addition and mainly, however, a sudden change in stiffness takes place, causing a greater accumulation of energy on the weaker story. The most common cases of such interruption, which usually occurs by virtue of size, form, or aesthetic reasons, are the following:

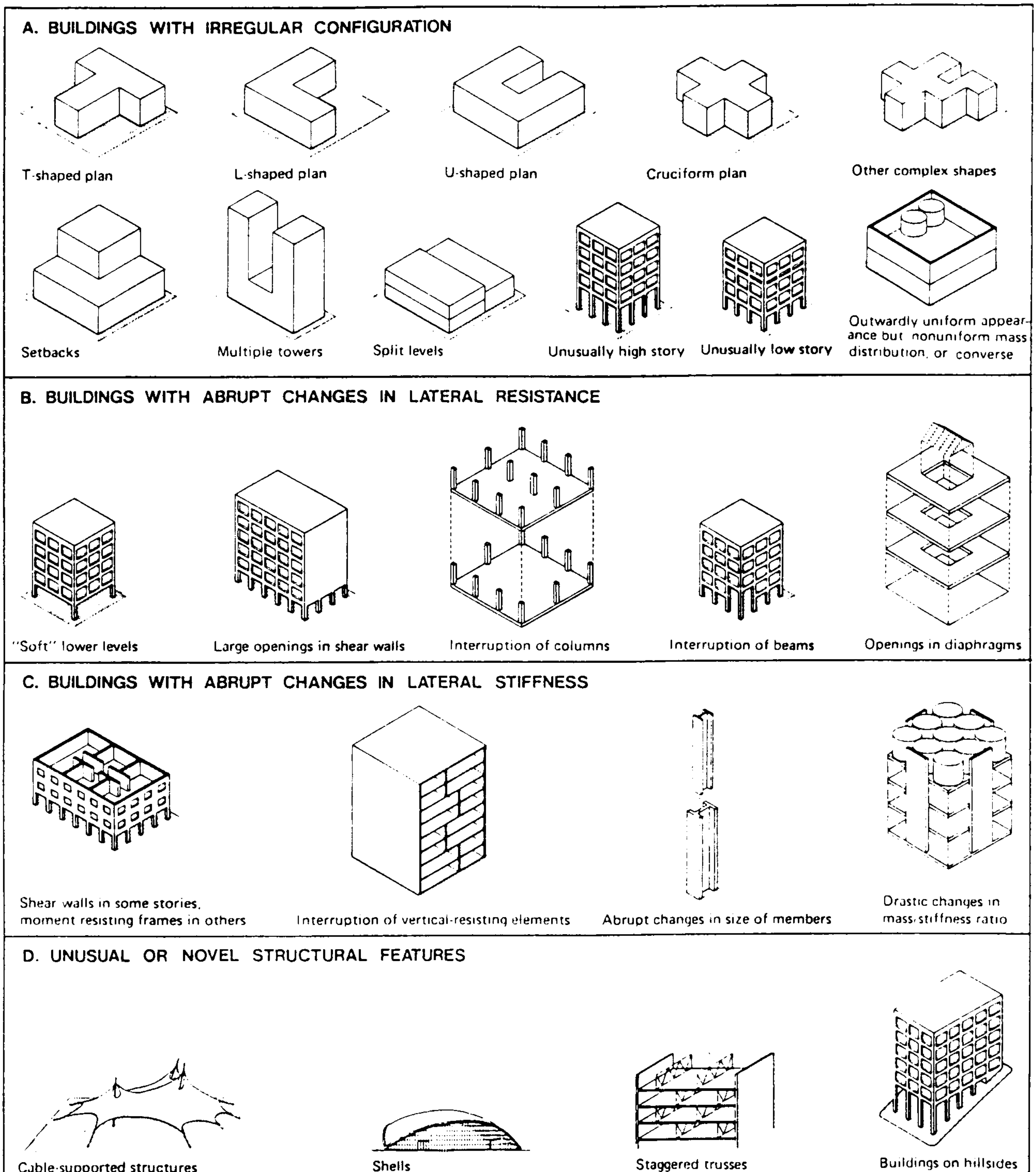
- Interruption of the columns.
- Interruption of structural walls (shear walls).
- Interruption of partition walls, conceived erroneously as nonstructural, aligned with frames.

Setbacks

Setbacks in the mass of a building are generally used because of city planning requirements relating to illumination, proportion, etc. However, from the standpoint of earthquakes, they cause sudden changes in stiffness and mass and accordingly give rise to the problems mentioned above of concentrating the destructive energy in the floors near the area of the sudden change. In general, the aim should be to make the transitions as smoothly as possible in order to avoid such concentration.

Inverted setbacks should be avoided in seismic areas, since they also involve a serious risk of overturning, as mentioned with the distribution of mass (see Figure 25).

FIGURE 25. IRREGULAR STRUCTURES



Graphic interpretation of "irregular structures or framing systems," from the Commentary to the *SEAOC Recommended Lateral Force Requirements and Commentary*. Reproduced in Arnold, Christopher and Reitherman, Robert, *Building Configuration and Seismic Design* (New York: John Wiley & Sons, 1982, p. 8). Reprinted with permission of John Wiley & Sons.

CHAPTER 4

FUNCTIONAL AND NONSTRUCTURAL VULNERABILITY OF HOSPITALS

FUNCTIONAL LOSS FROM NONSTRUCTURAL DAMAGE

The function of a hospital must be maintained after the occurrence of a strong earthquake in order to satisfy the needs for medical care occasioned by this kind of emergency situation. If a hospital suffers serious damages it cannot fulfill its function when most needed, since it becomes itself a casualty of the disaster.

The design of any structure subject to seismic movements should take into account the fact that the nonstructural elements of a building, such as ceilings, panels, windows, doors, etc., as well as mechanical and sanitary installations, must withstand the movements of the structure. Moreover, since the excitation of the nonstructural elements caused by movements of the structure is generally greater than the excitation at the foundation, nonstructural elements in many cases are more threatened than the structure itself.

The foregoing notwithstanding, the seismic design of structures usually attaches little importance to these elements, even to the extent that many design codes do not include relevant design standards. Perhaps because of this, the experience with recent tremors often demonstrates excellent behavior of structures designed in accordance with modern seismic-resistance criteria, although unfortunately accompanied by a poor response of the nonstructural elements. However, if the safety of the occupants of a building and of the pedestrians endangered by the collapse of such elements is taken into account, as well as the cost of replacing these elements and the losses involved in interrupting the operations of the building itself, the importance of giving due consideration to the seismic design of the nonstructural elements within the general layout of the building can readily be understood.

In the particular case of hospitals, the problem is of major importance for the following reasons:

- Hospital facilities should be maintained as intact as possible in the event of a severe earthquake because of their importance in responding to seismic disaster in the city or region in which they operate. This applies to both structural and nonstructural elements.
- At the time of an earthquake, hospitals house a large number of patients who are practically incapable of evacuating the building, in contrast to the occupants of any other kind of building. This means that the failure of nonstructural elements should not be tolerated in this type of structure, as it indeed appears to be in others.
- Hospitals contain a complex network of electric, mechanical, and sanitary facilities, as well as large amounts of usually expensive equipment, all of which are indispensable for their normal operation and for responding to an emergency. As a result, hospitals cannot allow the movement of the structure to bring about the failure of such facilities and equipment, which in turn could cause the functional collapse of the building.
- The ratio of the cost of the nonstructural elements to the total cost of the building is much higher in hospitals than in other buildings. Indeed, whereas in apartment and office buildings it is approximately 60%, in hospitals, mainly because of the cost of medical equipment and specialized facilities, it amounts to between 85% and 90%.

Because of the customary fragility of the materials used in the construction of architectural partitions, such as masonry, asbestos, glass, etc., building codes usually require limiting story drift for the purpose of indirectly ensuring protection of nonstructural elements attached to the diaphragms. The limit that the ATC-3 code accepts for hospitals is 0.01 times the free height from the floor, for the design earthquake. It may be assumed that compliance with this limit affords satisfactory indirect protection to high-quality nonstructural materials and construction.

However, if there are any doubts in this regard, it is a good idea to provide isolation systems for such elements of the structure so that they are not subjected to deformations.

In the case of windows, for example, the high fragility of glass makes it almost compulsory to provide adequate isolation. With respect to masonry walls joined to the structure, isolation should be considered with regard to the overall design concept of the structure. If the design does not consider these walls as part of the seismic resistance system and if they in turn cause torsion problems due to their asymmetric position or problems of soft stories due to their concentration on just a few stories—the most common problems—it is then appropriate to isolate them.

In the opposite case, that is, when the walls do not cause problems because of their arrangement in plan and elevation, they should be considered in the analysis as a part of the seismic-resistant structure. This fact is of great importance, since the seismic response of the construction as a whole may be very different from the response reported by a model that disregards the presence of the walls. Indeed, the variation in rigidity in the model leads to different design forces, both in moderate and severe earthquakes.

The decision regarding isolation of the masonry of the structure should be taken with care because of the need to ensure adequate anchorage of the masonry in order to compensate for its independence from the structure and to prevent collapse, which in the case of hospitals can be catastrophic. It is usually recommended that the masonry be isolated from the structure in the following cases:

- When its distribution in plan tends to cause extreme eccentricities in stiffness and, consequently, intense torques.
- When it tends to produce excessive stiffness of one or several floors with regard to the other floors, which, in this case, would become relatively weak.

STRUCTURAL DAMAGE DUE TO NONSTRUCTURAL COMPONENTS

There are three kinds of nonstructural components that can have a significant effect on the structural response of a building during an earthquake, even if the building is of seismic-resistant design. These are:

- Heavy equipment
- Architectural elements
- Mechanical installations

In the first case, a building with seismic-resistant design will have been analyzed, taking into account its dynamic behavior in accordance with its own weight. Heavy equipment, such as air-conditioning units, medical scanners, alternate generators, boilers, hydrotherapy pools, etc., can significantly change the dynamic response of a building, so that when an earthquake occurs the reactions may be different from those for which it was designed and constructed.

Such exceptional loads may produce stress on ceilings and floors that can cause catastrophic failures that will have an impact on the underlying diaphragms.

Such additional masses or weights may also produce eccentricities that subject the building to rotational modes of vibration during an earthquake. It is known that rotational modes of vibration can cause severe damage to a building, and unless they have been taken into account during the design, a building that will supposedly perform well in an earthquake may, on the contrary, suffer partial collapse.

It should be noted that if heavy equipment is not firmly anchored to a structural element of a building or to its foundations, it may slide, overturn, or move in such a way that it can cause structural damage. There are known cases in which boilers or heavy water heaters have moved, tearing down structural supports or walls and causing the collapse of the building.

With regard to architectural elements, the specific points to be looked into are unreinforced masonry infill and building facings. Although the unreinforced masonry infill is not usually considered to be a structural element, it nevertheless provides stiffness to a building until it begins to fail. If these segments of internal partitions fail irregularly, they may cause stress on columns and beams that was not foreseen in the design.

Consequently, the structural design should consider the effects of masonry infill during an earthquake when it begins to fail partially and thus dynamically alters the rigidity of the building while it is in movement.

If heavy facings on the outside of a building fall during earthquakes, and one side of the building loses a large part of its facing while another side does not, the imbalance may cause the building to twist. This torsion may not have been foreseen in the structural calculations and could result in partial collapse.

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

Another architectural problem that may affect the structure of a building is "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 design should enable them to resist earthquakes by ensuring that ground level columns are sufficiently strong and flexible. Sometimes these buildings are remodeled later on in order to close the open areas with masonry infill 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 the resistance with which they were originally constructed have been altered.

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

CHAPTER 5

MITIGATING NONSTRUCTURAL DAMAGE

INVENTORY, INSPECTION, AND EVALUATION

The first step in implementing a nonstructural disaster mitigation program for a hospital is to carry out a systematic and complete inspection of the facility in order to assess the existing hazards. The hazards should be classified into three categories and three levels of risk by determining if the elements under consideration represent (1) a risk for human lives; (2) a risk of property loss; or (3) a risk of functional loss. The risks in each case should be subsequently classified as low, moderate, or high (*16*, *17*).

A high risk for human life might be something such as a piece of equipment installed on the wall adjacent to the bed of a patient that in falling could injure or kill the patient. If the piece of equipment is not fastened down in any way—that is, if it is on a shelf, for example—the risk in the event of earthquake is high. If the item is fastened with bolts, but insecurely, the risk could be classified as moderate; and if it is fastened correctly with very little possibility of falling, it would be classified as low.

The loss of property would include something like a word processor in an office. It would probably not fall or injure anyone (although the possibility exists), and its loss would probably not affect the operation of the essential services of the hospital. However, it could be an expensive loss.

A functional loss might be an alternating-current generator. If it is not correctly fastened and/or enclosed it might move enough to disengage its electrical connections and be put out of commission. There may be no property loss because the equipment may not have been damaged but simply freed from its fastenings and connections. This would not represent a risk for human life, at least not directly, although almost the entire hospital depends on electric power for energy, including life support systems for critically ill patients. This demonstrates that in some cases, a piece of equipment may be associated with two or three types of risk or danger: for human lives, property, and/or functional losses (*18*).

Assessment of the types and levels of risk for any particular element in a hospital may be made by using an appropriate form that corresponds to the needs of the medical care center (see Table 2).

The form can be labeled as Patient Room, X-rays, Operating Room, Emergency Room, Physicians' Offices, Laboratory, Hallway, Supplies, Nurses' Station, Newborn Nursery, Kitchen, Parking Lot, Stairways, etc. The items that should be considered and classified could include lighting systems, panels in ceilings, equipment on wheels, file cabinets, special equipment installed in shelves or on walls, shelving, partitions, piping, chemicals, etc.

A note should be made in the box "Observations" or somewhere below if the nonstructural element is capable of constituting a potential hazard for the structure during an earthquake.

Certain interior nonstructural hazards that can affect the life or health of the occupants of a hospital are worthy of mention:

- Furniture with sharp edges
- Glass objects that may fly through the air and shatter on the floor
- Objects that fall from shelves, cabinets, and ceilings
- Impact by objects that slide or roll on the floor
- Inhalation of toxic or medical gases
- Contact with corrosive or dangerous liquids
- Electric shock
- Steam burns
- Fire
- Disconnection or failure of life support systems
- Inability to evacuate or be moved

Facility: XYZ OFFICE   Assumed Intensity: Severe

PRIORITY	NON STRUCTURAL ITEM	LOCATION	QUANTITY	VULNERABILITY			ESTIMATED RETROFIT COST, EACH ITEM	ESTIMATED RETROFIT COST, SUBTOTAL	NOTES
				(+)	($)	(@)			
4	Air conditioner	Roof	1	mod	25-75%	mod	$100	$100	Sits on springs; no seismic restraints.
5	Suspended ceiling	Throughout	5000 sq. ft.	mod	100%	mod	$.20/sq. ft.	$1,000	No diagonal wires.
1	Water heater	Utility room	1	high	100%	high	$50	$50	Gas fired; no flexible pipe; no anchorage.
3	Shelving	Storage room	40 lin. ft.	high	100%	low*	$200	$200	*Low because contents not essential; unanchored; 8 ft. high.
6	Freestanding partitions	Secretarial stations	20 @ 6 ft.	low	0.5%	low	0	0	Stable layout (returns).
2	Fluorescent lights	Offices and lobby	50	high	25-100%	mod	$1,500	$1,500	Fixtures rest loosely on ceiling grid.
								$2,850	

(+) HAZARD FOR MEDICAL TREATMENT OF PATIENTS   ($) DAMAGE BY % OF REPLACEMENT VALUE   (@) LEVEL OF NEED AFTER EARTHQUAKE

TABLE 2. SAMPLE FORM

REDUCTION OF VULNERABILITY

After identifying a potentially hazardous nonstructural element and establishing 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. A list follows below of 12 applicable mitigation measures that in many cases have proven to be effective (*19*). These general procedures, which have been used in many parts of the world, are:

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

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

Relocation. This 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 would also be better to keep bottles containing dangerous liquids on the floor, if possible.

Restricted mobilization. Restricting the extent to which certain objects, such as gas cylinders and electricity generators, can move is a good measure. It does not matter if cylinders shift as long as they do not fall and break their valves, releasing their contents under high pressure. It may seem desirable to install emergency alternating-current generators on springs to reduce noise and vibration when they are operating; however, such springs would amplify seismic movement. Consequently, restraining supports or chains should be placed around the springs in order to keep the generator from shifting or being knocked off its stand.

Anchorage. This 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 the forces of inertia that enter into play. A good example would be a water heater, of which there may be several in a hospital. They are heavy and can easily fall and break a water main, an electric cable, or a fuel line, and consequently constitute a fire or flood hazard. The simple solution is to utilize metal strips to fasten the lower and upper parts of the heater against a firm wall or some other support.

Flexible couplings. These are sometimes used between buildings and exterior tanks, between separate parts of the same building, and between buildings. They are used because the separate objects each move independently in response to an earthquake. Some move rapidly or at high frequencies, others slowly at low frequencies. If there is a tank outside the building with a rigid connection pipe between the two, 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 tube between the two would prevent ruptures of this kind.

Supports. Supports are appropriate in many cases. For example, ceilings are usually hung from cables that only withstand the force of gravity. When subjected to the multitude of horizontal and distorting forces produced by an earthquake, they easily fall. Although electrical boxes are not heavy, they sometimes have heavy lighting fixtures attached to them. If they fall they can produce serious accidents to those underneath them. Electric connections can also be torn out of the ceiling, thereby constituting a fire hazard.

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

Modification. It is sometimes possible *to modify* an object that represents a seismic hazard. For example, earth movements twist and distort a building, possibly causing the rigid glass of its windows to shatter and sharp glass splinters to fly. Rolls of clear plastic may be used to cover the internal surfaces and keep them from breaking and threatening the lives of those inside. The plastic is invisible and reduces the likelihood of a glass window causing injury.

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

Reinforcement. Reinforcement is feasible in many cases. For example, an unreinforced infill wall or an unreinforced chimney can be strengthened at no great cost by covering the surface with a wire mesh and by filling it in with cement or some other mixture. Not only will these nonstructural objects be protected against failures, but with infill walls the structural parts will also be strengthened.

Redundancy. It is a good idea to have *extra supplies* for emergencies. It is possible to store additional quantities of certain products in boxes in places that will be accessible after an earthquake.

Rapid response and repair. This 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 place. Parts are consequently 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. Spare parts for plumbing, electricity, and other repairs, together with the appropriate tools, could be kept on hand in a hospital so that if something is damaged, it can be easily repaired. This would be a last resort in mitigation, but it is necessary to have it ready *before* an earthquake and to carry out the rest of the plan afterwards. For example, water pipes may burst during an earthquake; it may be impossible to couple each of the pipes and take all the measures necessary to eliminate this risk altogether, but it should be possible to ensure that everything necessary for quick repair is at hand. With such planning before an earthquake it is possible to save the enormous cost of damage caused by water with a minimum investment in a few articles and by thinking beforehand about what might occur.

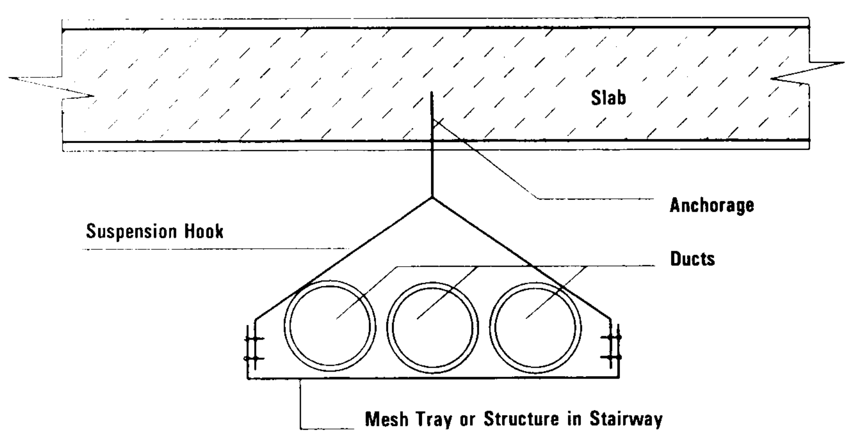
The general measures discussed above are applicable to almost all situations. However, in many cases, one simply has to be creative and devise one's own way of mitigating the effects of disasters.

Mitigation of damages in water and electrical installations

Water supply and electrical power installations are vulnerable points that in most cases are located in false ceilings. If special care is taken in building these networks by suspending them, for example, from mesh plates and anchoring special supports to the plates, these installations can be prevented from falling in the event of earthquake and hindering passage through hallways or affecting people in these areas. Another advantage provided by mesh support is the possibility of extending the rigid network, combined with expanses of flexible networks, every certain number of meters, thereby avoiding breakage of the network (*20*).

The same solution should be applied to vertical ducts, which, if appropriately located with sufficient spaces, can absorb seismic movement. It is also important to provide for doors in these ducts to provide access for changing parts (Figure 26).

FIGURE 26. DETAIL OF HANGING DUCT



One solution that has been used recently is to leave all mechanical installations on facades in full view. This allows not only for normal inspection of the installations but also for easy repair of breaks in case of disaster. It would also be desirable in individual rooms to plan mechanical installations for increasing the number of beds, if required. The same situation applies with regard to visiting areas and solariums. This makes it possible to double the number of beds, thereby improving the response capacity to emergency situations.

The extension of nurses' stations toward adjacent areas should be planned, thereby making it possible to house larger numbers of medical and paramedical personnel and allow them to work more comfortably.

Although the use of individual water heaters is not very frequent, when they are present they may be dangerous and vulnerable elements. In the event that such heaters do exist, they must be secured to the wall above and below with metal bands and bolts. Clearly, as mentioned before, the recommendation is made to heat water by solar energy, which would eliminate this kind of storage.

Hot water and steam in kitchen areas are potential hazards and consequently must be subjected to ongoing inspection by maintenance personnel to ensure that conduits are securely anchored and that there is no danger of escape.

A large portion of hospital equipment requires connections to electrical or mechanical systems. In the event of an earthquake an immediate inspection is required. Although the equipment may be appropriately installed, there may be sufficient differential movement to alter rigid connections. Such alteration may endanger the lives of the patients if essential equipment connected to water, steam, or gas networks malfunctions. The following are possible solutions to this eventuality:

- Flexible hose connections
- Movable connections
- Automatic shut-off valves

The following recommendations are made for electrical installations:

- Flexible conduits
- Rigidly-sealed cables and connectors designed to detect plug-in equipment without damaging it. It is desirable that most of the equipment be disconnected by means of a safety system instead of being operated with a grounded cable that might break.

Emergency plants are heavy objects highly subject to the forces of inertia during earthquakes. The heavier they are the more they are likely to move. If secure anchorage implies problems of noise and vibration, it should be verified that the springs are appropriately fastened. Spring mountings increase movement during an earthquake, which is why this should be taken into account in designing constraining measures. Movement of a generator can block entrances, displace structural parts, and sever electric power and fuel lines. Consequently, connections and installations should be handled in a special manner. In this case, flexible connections are recommended.

It was recommended previously that emergency plants be located in a special place. In addition:

- The plant should be anchored or restrained in such a way that it does not move or slide.
- The source of fuel should be available during movement.
- Start-up batteries or automatic input should be kept in perfect operating condition.

With regard to the availability of fuel to operate the generator, it should be verified that the motor is not connected to an exterior gas pipe. If an earthquake is sufficiently strong to interrupt electric power, it is also strong enough to interrupt gas supply. The supply of fuel should be continuous and be available at all times, regardless of the damages produced by any movement or accident. Replacement batteries should be on properly secured shelves to prevent them from falling.

Both internal and external communications should continue to function at all times. For this reason there is a need during emergency situations for having portable radio systems and loudspeakers on hand in order to organize both the users of the building and newcomers. Communications are also fundamental in maintaining contact with the outside, with other referral hospitals, and patients' family members. This service is less likely to fail if the hospital is designed along the lines suggested in the chapter on zoning, which indicated that this service could be located in a separate building.

Many pieces of equipment necessary in hospitals are suspended from the ceiling, as in the case of overhead lamps in Surgery and Obstetrics units, X-ray equipment with certain amperage, some exercise room therapy equipment, and extractors in kitchens and some laboratories. The recommendations of the manufacturers for anchorage should be closely followed, which in most cases specify special beams and bolts for suspending this equipment.

It is also recommended that furniture containing drugs, flasks, and containers have some kind of railing in front of each shelf so as to avoid the articles stored there from being spilled or causing obstacles.

Damage to installations seriously impede hospital operations, since they present an obstacle to the immediate actions required to mitigate emergencies. Consequently, they must be taken into account from the time the building is planned.

There are many mitigation issues that must be borne in mind in planning a health facility that do not apply to other kinds of buildings. Many damages are due to the collapse or the partial deterioration of the structure. However, cases exist in which a building has remained standing after an earthquake but has been put out of use because of nonstructural damage, whose costs are much higher than structural damages. Equipment, architectural finishes, and sanitary, electrical, mechanical, and telephone installations constitute the major cost of a health facility. It is worthwhile to reiterate the need to consider all mitigation factors from the birth of a project up until its completion so that adaptation or restoration after a disaster will be less costly.

The influence of architectural finishes

The selection of facings and finishes in a hospital is not only concerned with esthetics and durability but also with the mitigation of risk. This is very important because it is not only a question of the hospital failing structurally, but also of its finishes, walls, doors, windows, and ceilings, etc., remaining in place so that they do not become a danger to life or hinder the movements of patients, medical and paramedical personnel, and all other people in the building or those that enter the building in a time of disaster.

Ceilings are usually hung from the structure or floor slab of the building, and in hospitals this is an almost unavoidable feature, since the space formed between the ceiling and the floor slab houses the water, electric power, and gas networks. For this reason their construction should be as technically perfect as possible in order to avoid their becoming detached during an earthquake and posing a threat to the lives of the users of the building. The specifications of the ceiling should comply with aseptic standards and be made of non-flammable materials, that are light and capable of resisting movement. One of the recommended materials that fulfills these conditions and also serves as an acoustic and thermal insulator is fiberglass.

Nevertheless, areas exist whose functions do not permit the use of this kind of ceiling because of the rigorous necessity for asepsis. Examples of this are surgery and obstetrics areas, laboratories, humidification therapy, and kitchen and laundry areas for which thought must be given to solutions similar to those proposed, but with finishes that ensure asepsis, such as enameled materials and epoxy paints.

There is sometimes a need for sacrificing aesthetic considerations in order to meet the needs of mitigation; this is true in the case of roofs, especially in buildings for horizontal hospitals. A tile roof is quite heavy, which makes the roof more vulnerable to earthquakes; in addition, it contains multiple small elements that in falling would threaten the lives of the building's users.

Facades are commonly made of materials that may become detached during an earthquake. These materials, mostly of ceramic, also represent a threat to the lives of the users of the hospital. In order to mitigate this threat it is recommended that structural materials be used on facades, such as open-faced brick.

Most finishing pieces are also prefabricated and affixed to the facade. These elements are the first to fall in strong earthquakes, with all the attendant dangers previously mentioned. In order to avoid these risks,

- Anchorage should be firm in order to ensure stability;
- Solid materials should be used on building fronts.

Very large glass surfaces are dangerous in the event of earthquake, since they can be converted into weapons that threaten the lives of the users of a building. Designers can specify safety glass and/or reduce the size of panes. Flagpoles, signs, and pergolas are attached to the building, and consequently should be very well anchored to the masonry or the structure to avoid becoming additional risk factors.

There is a trend toward the use of prefabricated elements for railings on balconies, and in most cases sufficient anchorage is not specified for them to be integral elements of the building, increasing their likelihood of becoming detached. This is also true of other railings and banisters, etc. Such elements should be firmly anchored to the masonry or to the structure to prevent the risk of detachment.

Some designers decide to hang flower boxes on building facades, thereby increasing loads still further. These kinds of elements should not be used in hospitals.

Large spaces, such as entrance halls, are often lighted by means of hanging panels, which must be well anchored to the structure and overhead floor slab in order to ensure that they will remain in place when the building is subjected to strong movement.

At the present time large canopies are used in solariums, which in most cases are finished with glass and are extremely dangerous. Although acrylic or plexiglass panels are not fully safe, they can nevertheless be used with a greater degree of reliability in order to avoid the risk of accident when telluric movements occur and the components of the canopy fall.

There are many nonstructural finishes in building interiors that become additional risk factors for the users of the building, such as moldings, cornices, stucco ornaments, etc. In a great majority of cases they are attached to walls or columns, thereby constituting an additional hazard. It is recommended that a minimum number of such elements be used, and if they are used, that they be built as an integral part of the structure.

Hallways in hospitals often have wall protectors, which are usually made of wood and are attached to the walls with bolts every 50 or 80 centimeters. Special care must be taken to anchor these wall protectors to the wall to ensure that they do not become an obstacle and constitute a danger to free circulation.

Most hospitals have sign panels suspended from the floor slabs, particularly in information areas, nurses' stations, and at counters where the public is received. It is recommended that designers and builders propose designs that will provide more guarantees of safety and carefully specify the type of anchorage that should be used.

Materials that provide durability and asepsis are usually specified for hospitals, mostly in the form of enameled ceramic. These materials should also be firmly fastened to the wall in order to prevent detachment by seismic vibration. Although the danger of such materials causing accidents to users is minimal, they can become obstacles for the movement of hospital staff.

The situation is similar with regard to tables, mirrors, and furniture hung from the walls. It is important to take into account how they are anchored to or hung from the walls. In the case of furniture, it is recommended that wherever possible it should be embedded between walls and anchored, if possible, on both the sides and backs.

Hollow brick or cinder block is usually employed in nonsupporting walls between the structural support axes. Their collapse could cause injury or death. Consequently, the walls should be contained or interlocked in such a way that they provide better stability, as mentioned in the preceding chapter.

The same is true of spaces designed as open office cubicles, as they are made up of panels and shelving partitions. In some cases the furniture forms part of these partitions, which in falling can cause not only injury but also block traffic and evacuation. It is recommended that these partitions be secured above and below in order to provide a greater degree of safety and thus be able to avoid the risks referred to above.

The infinite range of factors that should be considered for the purpose of mitigating architectural risks is left to the reader's imagination.

Mitigation of damage to equipment

Today, objects or equipment inside hospitals are of great value, surpassing even the cost of the building. Most of these elements, including supplies, are essential for saving lives and can represent a danger in the event of an earthquake (*21*). A list follows below of some these elements:

Essential diagnostic equipment: Phonendoscopes, tensiometers, thermometers, otoscopes, ophthalmoscopes, reflex hammers, and flashlights should always be available for physicians, paramedics, and administrative staff.

Additional stocks are required for emergency situations. Such stocks should be located in an easily accessible place and clearly labeled in such a way that they can be easily located after a disaster by support personnel, volunteers, first aid units, etc.

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

Carts: Carts used to convey special equipment for crisis intervention are of special importance in saving lives and storing supplies. They are found in all patient care areas. The objects they contain should be fastened to the carts, and when they are not in use they should be braked and set against dividing walls.

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

Wheelchairs: Special spaces should be designed for wheelchairs near the nurses' stations so that the nurses can distribute them. Wheelchairs should have brakes on large wheels, the same as wheel stretchers.

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

Heavy objects: These include articles such as television sets on high brackets near beds, in waiting rooms, and in meeting areas. If they fall they are capable of producing serious accidents. Certain specialized objects have already been mentioned, such as X-ray equipment, ceiling lamps, and substations, which may be torn from their places if not firmly fastened.

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

Supports for phleboclysis equipment: Although in many cases this equipment is free-standing, for greater security it is recommended that it be attached to the bed.

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

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

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

Refrigerators: It is particularly important for the blood bank refrigerator to maintain continuous cooling, and consequently it should be connected to the emergency power supply. If such is not the case, the reserve blood supply will be lost, which is very much needed during emergency situations.

Nuclear medicine: This sector involves particularly hazardous situations, given the type of equipment and materials it uses, such as:

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

Radioactive materials are extremely hazardous, especially waste materials, whose radioactivity must not be ignored. They should be stored in airtight canisters.

Hospitals contain an infinite variety of potential dangers deriving from the equipment they use, and consequently it is essential to bear in mind that all implements, pieces of furniture, and medical apparatuses constitute a threat to life if they are not installed by adhering to the most stringent security measures in the following areas:

Therapy sector: It is impossible to control water spilling from hydrotherapy pools during strong earthquakes. For this reason, drainage must be provided for. The Exercise Room in Physical Therapy contains weights, counterweights, and springs, etc., that should be well fastened to avoid movement.

This area includes a large amount of equipment used for paraffin therapy, electrotherapy, nebulizers, steam compresses, etc., that must be firmly fastened to the floor or pieces of furniture to avoid danger in the event of disaster.

Kitchen area: As mentioned previously, the food service must be guaranteed in emergencies. Consequently, all kitchen equipment, such as pots, ovens, stoves, extractors, choppers, potato-peelers, industrial blenders, thermal carts, etc., should be firmly attached to slabs, walls, ceilings, etc., in order to ensure their operation and to prevent them from falling on their users.

The same is true with regard to the storage of foodstuffs and perishables. It is preferable not to store such goods in shelves by units, but rather in cardboard boxes or plastic baskets that are labeled and firmly fastened to the shelves.

The same precautions should be taken in the cafeteria, pantries, bakeries, and floor kitchens.

Spaces for fuels such as fuel-oil and gas should face outside patios in order to avoid explosions that might cause irreparable damages. They should also be managed under maximum safety conditions in strict adherence to the applicable standards.

Gas plant: It has been observed that inappropriate location of this service may constitute a time bomb. Consequently, proper safety standards must be applied in this regard, and the plant should be well ventilated and preferably located outside the building block. The front wall of the area should be free-standing and face spaces unoccupied by people in the event of explosion.

Gas cylinders are also used by some hospitals and dispersed through the building, mainly in the support areas. Some contain toxic and others inflammable gases, and consequently should be isolated in order to protect personnel or patients from injury or essential elements from damage.

General warehouse: Important materials for the operation of the hospital are stored in this space in depositories and subdepositories. These materials include drugs, among others, which are dispatched to the pharmacies. For this reason it is essential to observe good safety standards and ensure that shelving is firmly fixed to the floors, walls, and ceilings to avoid overturn.

Machinery room: This room's new location has already been dealt with. The equipment it contains should be made up of heavy units permanently anchored to ensure their proper functioning.

Maintenance workshops: Maintenance workshops are of great importance both in normal situations and in emergencies, since they are responsible for the repair of a large number of electrical, sanitary, and plumbing installations, etc., that are necessary in the event of building damage. The stock of materials to be maintained by this workshop should be calculated to cover emergency situations; and safety conditions, as described for other sectors, should be maintained with regard to the storage and anchorage of machinery.

Signposting: There is a great need for good signposting in a hospital, not only to guide users in using the services, but also in evacuating the building in time of disaster. The strategic location of signs should indicate evacuation routes through emergency stairs and uncommonly used exits designed especially for such cases. In addition, the location of fire extinguishers, fire hoses, fire-fighting equipment, fire doors, and emergency telephones should be clearly indicated. Efficient evacuation of a building depends on good signposting. Signposting should not only include the interior of the building but also the outside and the surrounding urban area so that the location of the hospital is clearly indicated from any point in the city. Emergency supplies should include signposts indicating the hospital services both inside and outside. Routes in each of the hospital's areas should be indicated by colored bands strategically placed on floors or walls.

It would be practically impossible to make a complete list of all the elements involved in the operation of a hospital. Consequently, in designing disaster mitigation measures, common sense must be used, since varying factors in every hospital determine the particular solutions required. Among other elements that have not been mentioned specifically and that may prove to be life threatening are (*20*):

- Traction units
- Portable oxygen and other medical gas cylinders
- Immobilizing frames
- Deionizers
- Medications carts
- Automatic dispensing machines
- Laboratory analyzers
- Drying ovens
- Microscopes
- Distilled water in glass containers
- Film illuminators
- Kettles and steamers
- Patient tray delivery carts
- Carts
- Refrigerators
- Chairs and stools
- Hyper- and hypothermy machines
- Patient hygiene materials
- Hemodialysis machines
- Circo-electric beds
- Dialyzer tanks
- Teleautographs
- Portable fume hoods
- Pharmaceuticals and other supplies
- Laboratory glassware
- Incubators
- Washing machines and sterilizers
- Centrifuges
- X-ray machines, fixed and portable
- Formaldehyde, alcohol, paraffin, etc.
- Chemicals for film development
- Film files
- Ovens
- Mixers
- Potwashing machines
- Pot racks
- Fire extinguishers
- Desks
- Cleaning supplies

The above list gives an idea of how long and tedious it would be to carry out a complete investigation for the purpose of mitigation of the risks of earthquake and other kinds of disaster. Consequently, it is more a matter of formulating concerns that can be expanded and prepared over time. Each person and agency can add their own procedures, adding new concerns and solutions—on the condition, of course, that priorities are established, since it would be almost impossible to accomplish everything that might be needed. Any progress represents an important step toward mitigation and, therefore, toward reducing risk factors and reducing the possibility of the functions of a hospital being lost when they are most needed.

CHAPTER 6

UNIVERSITY AND PROFESSIONAL TRAINING

CURRICULUM REFORM

Hospital architecture in Latin America has generally been overlooked, which is not the case in industrialized countries. With the exception of a few cases, no generalized effort has been made to promote formal education in this area. This is even more true with regard to focusing on mitigating risks and preventing disasters in the courses in hospital design given in the Region's architecture schools, since the subject is a relatively new one and has not generally been considered in these kinds of courses throughout the world.

The design of hospitals, as is the case with other essential structures, should be taught at both the undergraduate and graduate levels. In the first case, in order to make professionals aware of how important the operations of this kind of facility are, and in the second, in order to determine the most appropriate design requirements on the basis of the cost analysis, safety, and operational considerations that each case requires. An educational strategy of the type recommended does not necessarily lead to significant results in the short-term, but does contribute to conceptual change and a change in the attitudes of future professionals.

As has been noted, increased research and analysis must be undertaken for the purpose of exploring all possible facets of mitigation of risks so that there is awareness with regard to disaster mitigation and the planning and design of hospitals on the part of the new generations of architects, designers, and builders.

A certain resistance is frequently observed to including new subjects in programs of study in architecture schools, and it is necessary to demonstrate the importance and relevance of the subject in professional practice. Experience indicates that the process usually begins with the particular interest of a certain teacher or as a result of conferences or seminars that stimulate general interest. In this regard, individual events can play a fundamental role, such as a recent earthquake, which can be the catalyst for the start of these activities within the university.

It is important to mention the close relationship that engineers working with structural design and plumbing, electrical, and gas facilities ought to have with architectural designers, which is the reason why the subject should also be dealt with in a multidisciplinary manner. As already mentioned, once the need for examining the subject has been made clear, it will be less difficult to incorporate it into study programs.

Curriculum reform in architecture should consider two different areas: planning and design.

In the area of planning, geographic, demographic, and socioeconomic needs should be considered that will lead to a feasibility project that will involve changing some of the models traditionally employed in favor of incorporating new considerations relating to disaster mitigation.

In the area of design, research should be promoted that will implement all the proposals made in the planning phase for the purpose of translating them into architectural solutions. As previously noted, this is not possible without recruiting professionals from the fields of medicine, nursing, economics, engineering, etc., to make up the multidisciplinary teams that will devise the overall solutions. The integrating function of the architect can thus provide complete alternatives that will minimize the risk factors in buildings designed to house health facilities.

This work could be carried out at the undergraduate level in the advanced phase of design, in which hospitals are occasionally the subject of a design and planning exercise. Establishment of a graduate course would entail still greater efforts, since planning at this level involves a series of synchronized actions to be carried out by highly experienced professionals in various disciplines and additional expenditures to cover the costs of dissemination, information, bulletins, and audiovisual and programming material. A graduate course would envisage a two-year study program that would include research and practice in planning and designing of hospitals by areas.

It must also be stated here that the seismic design of a hospital is a responsibility that is shared between architectural form and resistant structural systems, and that it would be ideal if these shared relations could be understood by every designer who works in hazard-prone areas. Unfortunately, at the international level, educational methods and practice have tended to limit the opportunities for promoting this kind of understanding in minds of designers, since the instruction that new architects receive is separate from that of new engineers, and in many cases remains separated even in practice. Some architects have an intuitive understanding of structure, but they are very few, and this felicitous understanding tends to occur despite their training and practice, and not as a result of them. Incorporating this aspect in the training of architects in courses on structures and construction from the lower levels through the undergraduate level is useful not only in hospital design, but also in the general design of buildings in seismic areas.

The subject of mitigation of risks in architectural planning and design should be introduced into all schools and courses related to the field of health in order to educate all professionals in these disciplines regarding the needs and shortcomings of the various areas and services of a hospital. This strategy will ensure that these professionals will be in a position to demand that planners and designers fulfill the standards necessary to guarantee disaster mitigation.

CONTINUING EDUCATION

Since formal education does not produce tangible results in the short term, a strategy needs to be developed to impart knowledge to practicing professionals, be they staff members in a health facility, consultants, or educators in the health sector.

Inasmuch as the most effective strategy for incorporating the subject of disaster mitigation into study programs in architecture schools is to promote training and continuing education, acquainting professional associations and undergraduate and graduate student to the subject is an essential step toward promoting curriculum reform.

Short courses in continuing education and lectures on the performance of hospitals under seismic loads at congresses, symposia, seminars, and workshops on architecture, seismic engineering, reinforced concrete, construction, etc., can awaken the interest of professionals involved in hospital construction and, in many cases, train them to give due consideration to risk mitigation in existing health facilities and in designing new buildings.

Lectures can be organized to deal with subjects such as the development of new planning techniques for hospitals located in seismic areas, architectural seismic design of hospitals, development of techniques to reconsider the use of space for the purpose of emergency care and mitigation of risks, updating risk analysis and seismic microzoning for the purpose of siting health facilities appropriately, assessing the functional vulnerability of hospitals, and analyzing the vulnerability of existing hospitals, among others. These subjects could be presented on the initiative of concerned educators or by a group of knowledgeable professionals in order to assist health sector institutions in organizing seminars and congresses to focus on the subject of disaster mitigation and thus to create concern and increase the number of interested parties.

Professional associations and universities can assist greatly by infusing this process of professional training with seriousness and a sense of responsibility, thereby expanding the coverage that can be achieved within institutions. This educational strategy is also an excellent technique for bringing together experiences and proposing alternatives to formal education.

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ANNEX 1

CASE STUDY OF SEISMIC DESIGN*

VETERANS ADMINISTRATION HOSPITAL

Case Study of Seismic Design in Hospital Architecture

An internationally known example of hospital architectural design, which stands out because it unites various aspects of seismic risk mitigation, is the Veterans Administration Hospital in Loma Linda, California.

The site for this hospital complex was chosen after a detailed analysis of the potential sites available in a region that has 11 known active faults within a 65-mile radius, including the San Jacinto fault and two segments of the San Andreas fault. Intensive seismic studies indicated that, although the Loma Linda fault was in close proximity to the chosen location, it was 200 to 400 feet southwest of the site and surface rupture at the site was not likely.

The building structure was designed for a peak acceleration of 0.5 g and its nonstructural components for an acceleration of 2.0 g.

The primary considerations for building configuration were as follows:

*1. **Site geometry:*** The 40-acre site allowed the designers to consider a free-standing building unrestricted by site geometry. The site area was large enough to accommodate a low building, laid out horizontally.

*2. **Programmatic considerations:*** Research studies on hospital organization and planning carried out by architects before the Loma Linda project pointed to some of the advantages of horizontal planning, defined as plans in which clinical and diagnostic areas are placed on the same floor as patient care areas, instead of being concentrated in a base structure with a vertical connection to bed-related functions.

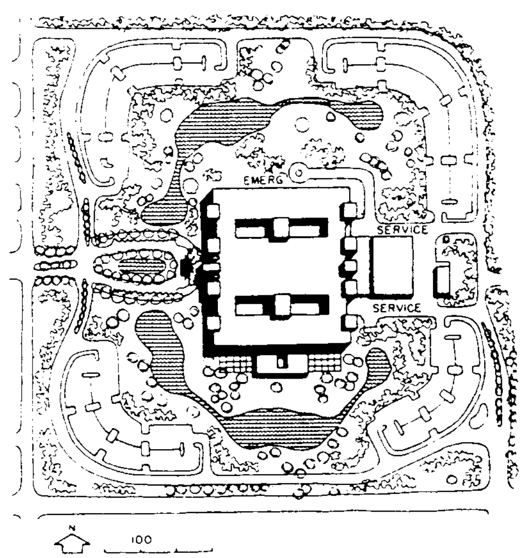
The advantages related generally to internal transportation questions, which were studied separately by the architects during the schematic design phase of the Loma Linda Hospital under a separate contract from the Veterans Administration. Experience in vertically planned VA hospitals had

*Adapted from: Arnold, Christopher and Reitherman, Robert. *Building Configuration and Seismic Design* (John Wiley & Sons, New York: 1982, pp.216-222). Reprinted with permission of John Wiley & Sons.

indicated some problems with providing for adequate circulation, since the concentration of vertical circulation in a single tower tended to result in over- or under-capacity, depending on the time of day. Hospital staff also showed a general preference for horizontal as opposed to vertical movement, and there were indications that it would be desirable to reduce vertical circulation for severely ill patients, for example, during the pre- and postoperative period.

3. Aesthetics: Hospital design tends to be dominated by the need to solve very complex planning, service, and equipment problems, making appearance a secondary consideration. The city of Loma Linda wanted the hospital site to be "parklike." In response to this desire, and given the relatively small scale of the site's immediate surroundings, it seemed appropriate to envision a low building, blending into its surroundings, placed toward the middle of the site (Figure A.1). The building, because of its nearly 700,000 square feet, would be large, but its relatively low height and large site would help to reduce its impact on the community.

FIGURE A.1. THE LARGE, PARKLIKE SITE PLAN OF LOMA LINDA VETERANS ADMINISTRATION HOSPITAL



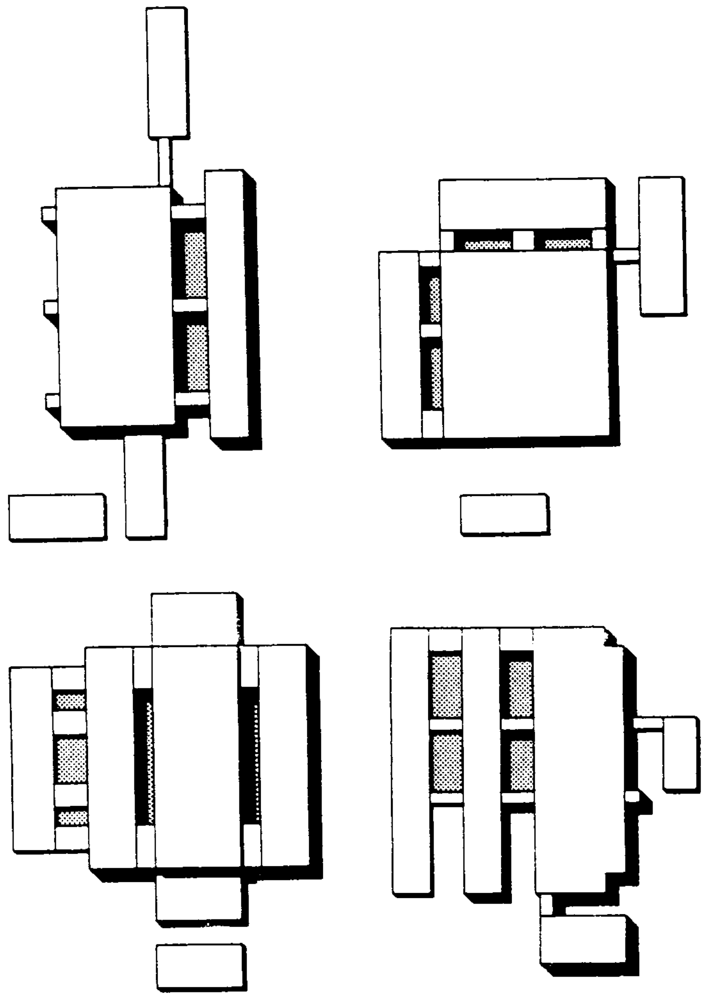
4. Building system: The building was proposed as a demonstration of the Veterans Administration Building System, which was developed over several years by the same advisory team responsible for the design of this hospital. The building system consisted of a set of carefully crafted design concepts aimed at rationalizing and organizing the preliminary hospital design.

The structural features of the system consisted of a moderate-span simple post and beam shallow floor framing system, large floor-to-floor heights, and lateral force resistance elements concentrated in the service tower and at the end of each of the service modules that together made up each floor of the building. The possibility that the system could be used under the extreme seismic conditions found in Loma Linda had not been anticipated, but the structural approach allowed the stringent seismic requirements to be met successfully.

Planning and aesthetic requirements, then, made a low, wide building desirable, which coincided very well with a stiff seismic design that would minimize story drift, and the consequent architectural, mechanical, electrical, and contents damage, and loss of operating capacity. In addition, a low, stiff building would have a shorter vibration period and a potentially lower response than the projected response spectra peaks from the nearby geographical faults.

The preceding requirements were specifically expressed by the structural engineers as a preferred design of no more than four floors, symmetrical in two plan axes and in section. Any complex configuration would be subdivided so as to allow each component, as far as possible, to accommodate these requirements. Accordingly, the architects carefully studied various schemes using single and multiple buildings of three, four, and five stories, with full basement, half basement or no basement. To assess seismic resistance, consideration was given to symmetry, shear wall availability, separation joint requirements, and continuity of vertical stiffnesses (Figure A.2).

FIGURE A.2. PRELIMINARY ALTERNATIVE SCHEMATIC DESIGNS STUDIED BY THE ARCHITECTS



All solutions that included basements produced vertical stiffness discontinuity at the first floor level. Multiple building solutions required a number of connecting bridges to maintain reasonable circulation and these in turn required a number of seismic joints.

The chosen configuration was the simplest of all those studied: a simple block, almost square in plan, with no basement and with four symmetrically placed courtyards within the block. The courtyards were relatively small. The plan had evenly distributed shear walls throughout, running uninterrupted from roof to foundation and having direct continuity in plan with the structural framing members (Figures A.3-A.5).

FIGURE A.3. SECTION THROUGH COURTYARDS, SHOWING SHEAR WALLS AT END

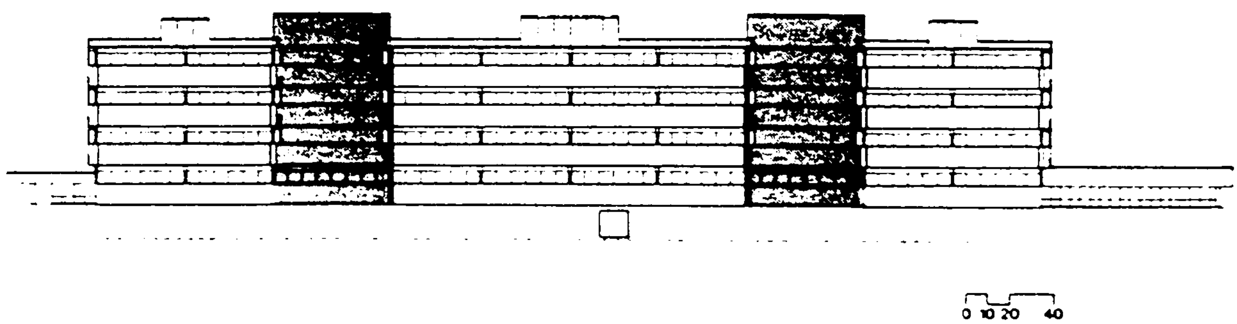


FIGURE A.4. TYPICAL STRUCTURAL FRAMING PLAN

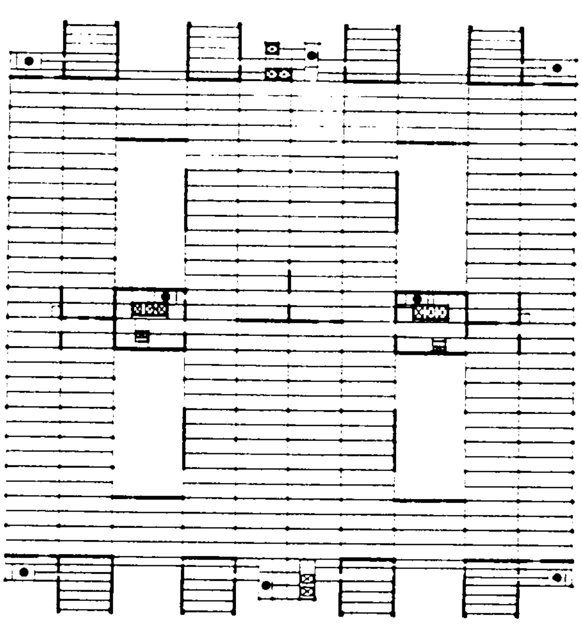
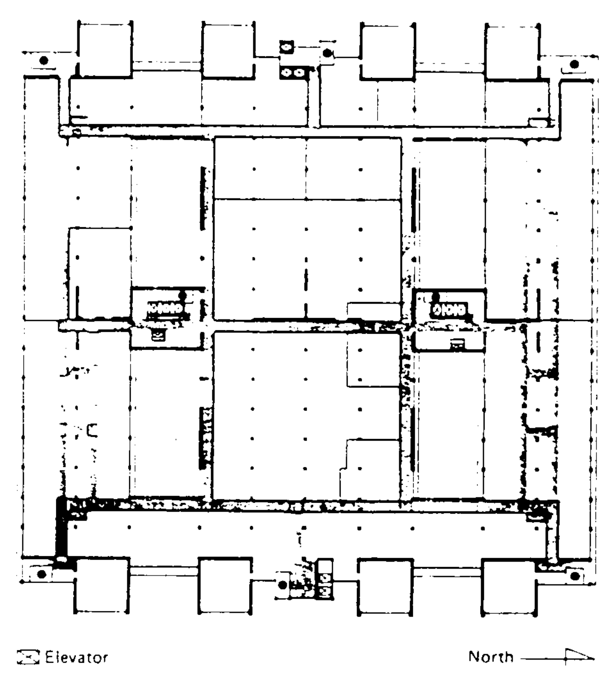
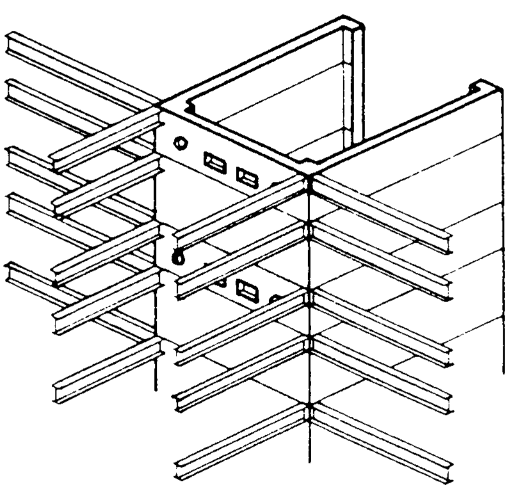


FIGURE A.5. THIRD-FLOOR PLAN, SHOWING CIRCULATION PATTERN



The planning and circulation of the building were carefully related to shear wall layout so that there was minimum shear wall penetration, and the departmental and public planning were clearly defined and highly accessible. The final result was notably uncompromised in both categories. The eight service towers (four at each end) provide a location for the major shear walls. Each tower provides two east-west shear walls and one in the north-south direction. The latter is an interior wall penetrated by large ducts and other horizontal services. However, these openings are repetitive and carefully controlled, and the use of an interior wall allowed these shear walls to be continuous with the perimeter framing of the building. This would not have been the case if the end walls of the tower had been used (Figure A.6).

FIGURE A.6. CAREFUL PENETRATION OF SHEAR WALLS WITH OPENINGS FOR CORRIDORS AND SERVICE DUCTS



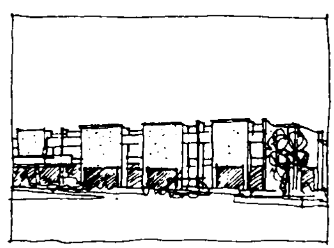
The general lateral resisting system used concrete shear walls and a ductile moment-resistant "back-up" frame. The stiff primary shear wall system was designed for a high force level, so that the structure would tend to have low lateral deflections for the design earthquakes mentioned earlier. The maximum story-to-story drift calculated was 0.004H, well within presently accepted desirable ranges for hospitals.

This hospital design was thus satisfactorily and harmoniously completed, and met all the requirements of an ideal design, since the engineers and architects worked together from the beginning of the project and were able to integrate all the aspects needed to ensure that the hospital would continue to function even in the event of a severe earthquake.

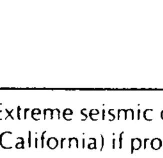
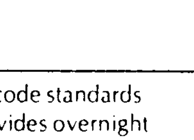
Annex 2

FORM AND VOLUME OF BUILDINGS*

Medical Facility, Low-Rise

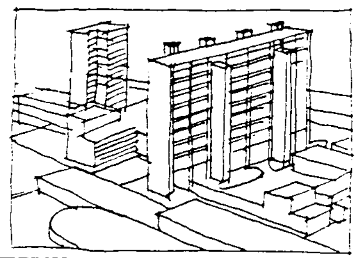


hospital
health clinic

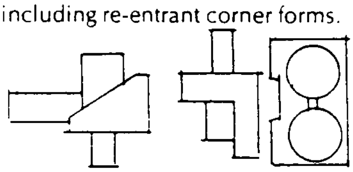
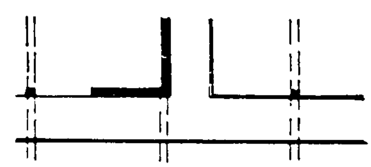
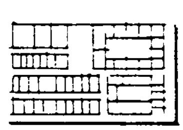
Typical Architectural Characteristics	Seismic Design Implications	Seismic Design Solutions
Great variety of configurations.	Variety of appropriate seismic design approaches.	Shear walls, frames, combinations.
Predominantly small rooms. Often complex planning requirements. May be nonrepetitive plan from floor to floor.  	Possible difficulty in maintaining uniform framing, shear wall location within each floor and floor to floor. However, forces in low-rise structure are fairly small because of low mass, so extent of bracing and shear walls not great.	Moment-resistant frame structure ideal to provide maximum adaptability of planning, but check drift limits. **Shear walls must be continuous.** Manipulate plan to achieve this.
Facility function dependent on equipment and utilities.	Structural design to reduce seismic effect on nonstructural components. Design seismic protection for equipment and utilities.	Design building for stiffness and low drift limits. Careful detailing of equipment and utility relationship to building structure. Check for overturning.
Extreme seismic code standards (California) if provides overnight care.	Rigorous plan checking and site inspection by state increases cost and design time.	Serious consideration of seismic issues from design inception essential.

*Arnold, Christopher and Reitherman, Robert, *Building Configuration and Seismic Design* (John Wiley & Sons, New York: 1982, pp. 169-170). Reprinted with permission of John Wiley & Sons.

Medical Facility, Medium- to High-Rise



hospital

Typical Architectural Characteristics	Seismic Design Implications	Seismic Design Solutions
Large variety of configuration types, including re-entrant corner forms. 	Possibility of stress concentration, torsion.	Subdivide by seismic joints.
Complex planning requirements: much horizontal and vertical movement of people, materials and equipment.	Limitations on placement of shear wall and bracing; must be related to circulation.	Careful planning relationships between shear walls, bracing and circulation. 
Large elevators result in large vertical circulation cores.	See High-rise offices, but larger cores increase shear wall possibilities.	See High-rise offices.
Large clinical and diagnostic areas need many small rooms, perimeter location not essential. 	Generally large floor area may result in need for interior shear walls, braces.	Care in locating shear walls, braces to permit planning function.
Hospital function very dependent on equipment and utilities.	Structural design to reduce seismic effect on nonstructural components. Design seismic protection for equipment and utilities.	Design stiff structure to limit drift, best done by shear walls or frames. Interstitial framing may be beneficial in limiting story drift. Careful detailing of equipment and utility relationship to building structure. Check for overturning.
Extreme seismic code standards (California).	Rigorous plan checking and site inspection by state increases cost and design time.	Serious consideration of seismic issues from design inception essential.

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