Smart technical guideline on base isolation in Hospital Design

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Introduction

Hospitals are critical facilities which provide much needed health services in areas following the impact of earthquakes. Hospitals are also very expensive with very high capital constructions costs and recurring operational expenses.

The only construction technology which exists that allow hospitals to remain fully functional and undamaged after earthquakes is base isolation.

This brief annex will present the fundamentals of base isolation and the need for ensuring hospitals located in seismic prone areas are built with base isolation systems.

This Annex is prepared as a guidance for the Technical Project Units of the Ministry of Health in countries.

Objective of Base Isolation

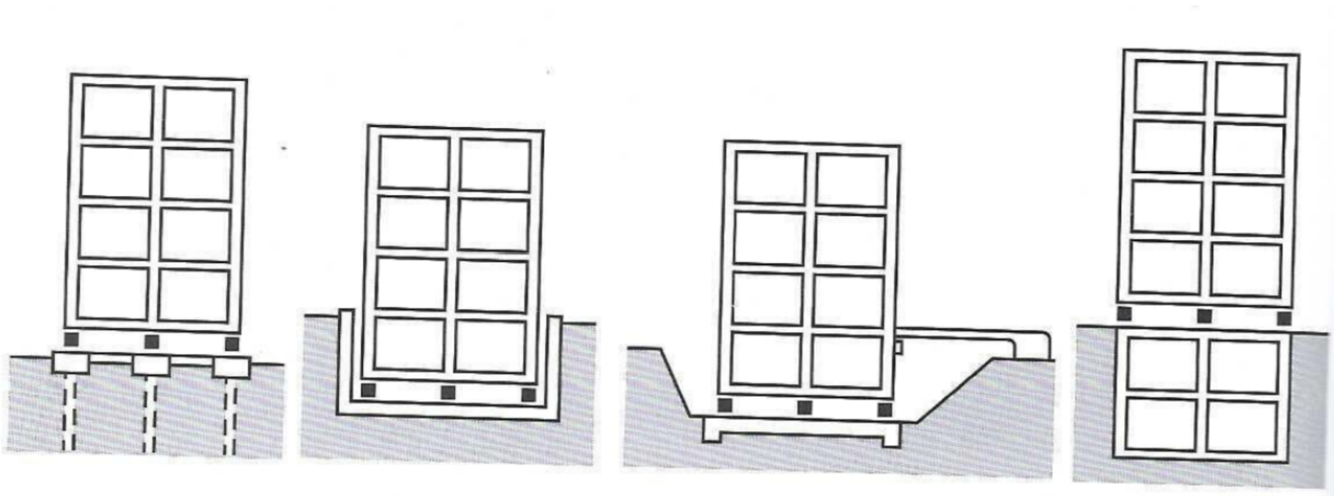
The purpose of using base isolation in hospitals is for safety in terms of seismic resilience, and functionality in terms of continuation of operational and medical services during and immediately following earthquakes. Base isolation has the added advantage of protecting the capital investment of the hospital infrastructure.

There are many seismically active countries which set precedence, if not mandated by law, for the use of base isolation in the design and construction of hospitals including Turkey, New Zealand, Japan (which has the highest number of base isolated buildings in the world), China, Mexico, Chile, Italy, Greece, India and the USA in states such as California.

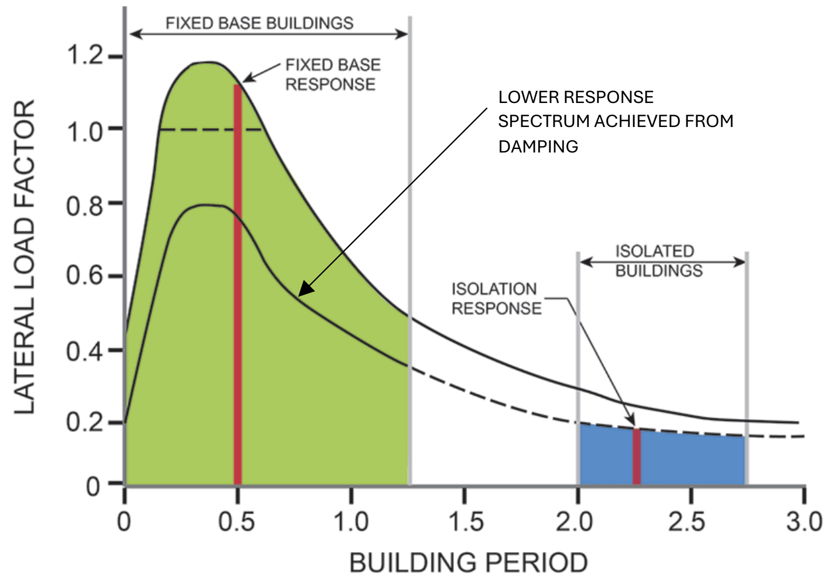
There are currently no hospitals or buildings in the English-speaking Caribbean with base isolation technology despite being a region with moderate to high seismic risk. Dominican Republic has several applications of base isolated buildings.

How base isolation works

The seismic isolators or bearings are located at the base of the building or within a storey to effectively separate the structure from the earth. When there is an earthquake with violent horizontal shaking, a building will sway back and forth because of the nature of earthquake forces (alternating forces). The time it takes the building to *naturally* sway back and forth once, is the fundamental period. Seismic base isolation systems use bearings which absorb these earthquake forces and elongates the fundamental period experienced by the structure and provides a significant contribution to damp the earthquake-induced lateral oscillations. The elongation of the building period reduces the seismic base shear experienced by the structure as illustrated in Figures 1 to 3 below.



[1]*Figure 1 - Different positions of base isolators at 'base' of building*



[2]*Figure 2 - Graph illustrates the typical seismic base shear factor experienced by traditional fixed based structures compared with base isolated structures with elongated fundamental periods.*

In engineering terms, the seismic base shear equation in building code-based approaches is:

$$V = C_s \cdot W$$

V = Base shear (total sideways earthquake force at the base of building)

W = total seismic weight of the building (self-weight + part of live loads)

Cs = seismic response coefficient which depends on soil conditions, ground shaking and the building period, T

For most building codes, the relationship between C_s and building period, T is:

[1] PAHO's Design Manual for Health Services Facilities in the Caribbean, Figure Ap2, page xxvi
[2] Seismic Isolation – The Gold Standard of Seismic Protection by M. Walters, 2015, https://www.structuremag.org/article/seismic-isolation-the-gold-standard-of-seismic-protection/ accessed 19Aug25

$$C_s = \frac{S_a(T)}{R/I_e}$$

$S_a(T)$ = spectral acceleration in other words, how much shaking from the ground passes the building at its period T

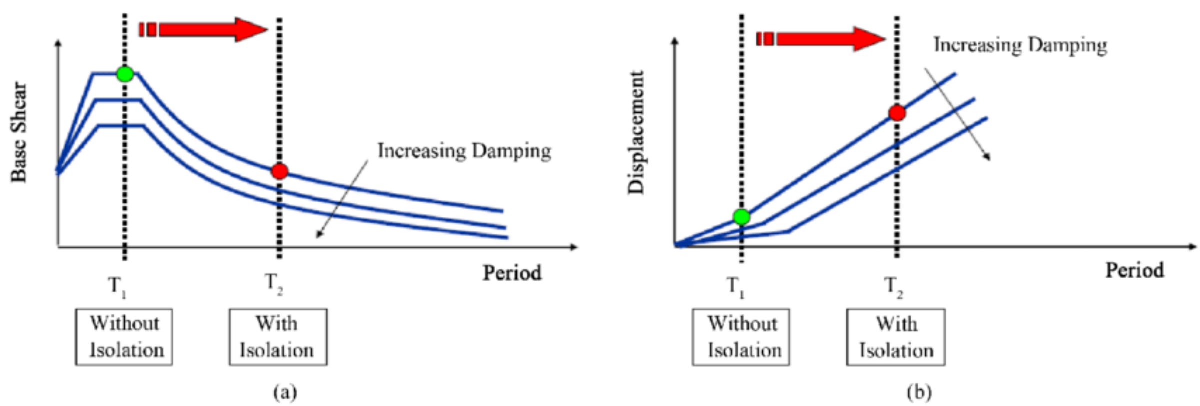
R = response modification factor (ductility/strength factor based on the building structural system)

I_e = importance factor, for example, hospitals and schools have higher importance factor than residential buildings.

Buildings with small fundamental periods, **small T → big $S_a(T)$ →big C_s → big V** (base shear or lateral load factor in Figure 1)

Buildings with large T (usually tall flexible buildings): **large T → smaller $S_a(T)$ →smaller C_s → smaller V**

The longer building periods achieved from base isolator bearings result in larger horizontal displacements of the building structure. These horizontal displacements require space around the structure to prevent pounding and flexible connections for all of the auxiliary services which supply this hospital building such as water, electrical, oxygen, refrigeration, and telecommunication. The damping capacity of the bearings and additional passive damping can be used to reduce the relative displacement of the building.



[3]*Figure 3 - Graph (a) illustrates same concept at Figure 1 of base shear vs period. Graph (b) illustrates the increased displacement experienced on base isolated buildings.*

Constraints of Base Isolation Systems

- Soft soils, with shear velocities less than 150m/s, pose additional design challenges and costs of using base isolation systems. Conversely very stiff soils, with shear velocities greater than 250 m/s may not provide the effective design seismic isolation benefits.
- All the services crossing the level of the supports (elevators, staircases, pipes, conduits, *etc*) or joining the building with its immediate surroundings (road/telephone/electricity networks, external steps, *etc*) have to be designed so as to tolerate without damage the relative displacement of the superstructure and the

[3] Open Journal of Earthquake Research, 'The Behaviour of Multi-Story Buildings Seismically Isolated System Hybrid Isolation (Friction, Rubber and with the Addition of Rotational Friction Dampers)', 2015 by A. Barmo, I. Mualla, H. Hasan.

foundations. These measures are particularly important when designing the infrastructure for gas, fire protection and waste-disposal.

- Separation joints may be very wide. The possible separation joints between two buildings or parts of a building on isolators need to be wide enough to account for the combined lateral displacements of the individual blocks.
- Future changes to the structure may be limited or incur high adaption costs involving design professionals. Changes to the partitions, façades and other heavy or stiff components should not significantly change the building's original dynamic behaviour which would have been taken into consideration for determining the selection of the base isolators.
- Access points or walkways between the surrounding ground and the base isolated structure may need to be repaired or modified post-earthquake depending on the building displacement during the event.

Base Isolation System Selection

There are different types of isolators or seismic isolation bearings available for buildings. These include primarily elastomeric bearings, sliding bearings and friction pendulum systems. They each offer different levels of damping and energy dissipation.

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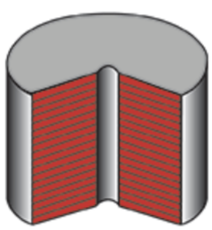
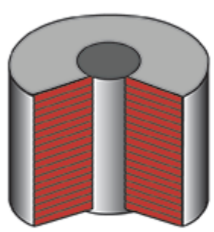
<tr><td>
High-Damping Rubber</td><td>
Lead Core Rubber</td><td></td></tr>
<tr><td colspan="2">[4]Illustration of elastomeric high-damping rubber bearings (HDRB) which are a sandwich of vulcanised rubber and lead plates. LRB is an HDRB bearing with a lead core.</td><td>Image of high-damping rubber bearing (HDRB) base isolator manufactured by FIPMEC, Italy.</td></tr>
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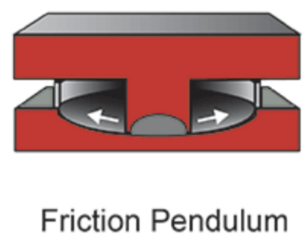
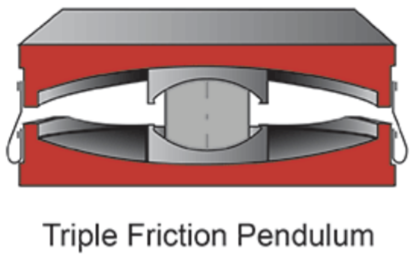
[4] Seismic Isolation – The Gold Standard of Seismic Protection by M. Walters, 2015, https://www.structuremag.org/article/seismic-isolation-the-gold-standard-of-seismic-protection/ accessed 13Aug25

		
[5]Illustration of friction pendulum bearings (FPB) which use a sliding mechanism between two spherical concave plates.		Image of friction pendulum bearing manufactured by FIPMEC, Italy.

Selection of the appropriate system depends on several criteria such as the building weight, seismic zone, ground site conditions and the amount of displacement allowed for the building and financial costs. The design team who will comprise of structural engineers with expertise in base isolation design, will review the ground conditions from geotechnical assessments and the various constraints of the site location and the specifications of available isolators to determine the most feasible base isolation system for the hospital. Input from the design team's architect, mechanical and electrical engineers, and the client are important in the final design outcome of the system.

High-damping rubber bearings (HDRB) are generally better option for hospitals over friction pendulum bearings, because they require less maintenance and offer smaller displacements suitable for hospital buildings.

[5] Seismic Isolation – The Gold Standard of Seismic Protection by M. Walters, 2015, https://www.structuremag.org/article/seismic-isolation-the-gold-standard-of-seismic-protection/ accessed 13Aug25

Performance Objectives

The primary objectives in the use of base isolation systems are

- life safety,
- minimise damage, and
- immediate occupancy following earthquakes (essential for hospitals).

The table below compares the performance of a traditional hospital design versus base-isolated hospitals.

Criteria	Traditional Hospital Design	Base-Isolated Hospital Design
Structural safety	Protect life safety, however structure may be damaged resulting in down time.	Protects life safety as well as building protection.
Non-structural protection	High risk of loss or damage equipment/utility and non-structural elements such as ceilings, partition walls, etc. Backup power and lifeline systems may be damaged.	Strong protection of equipment/utilities and mitigates damages to non-structural elements. Design includes flexible connections to protect generators, fuel supply, water lines and medical gas systems.
Functionality post-quake	Often non-operational	Remains operational. Services may continue uninterrupted in emergency units, ICU's and surgery. Added advantage is base-isolation systems minimise disturbance to sensitive medical equipment such as MRI's.
Patient safety	Safe from collapse, but patients and services may need to relocate to undamaged facilities.	Safe from collapse and stable environment to continue normal operations.
Downtime	Weeks–months	Hours–days (minimal)
Cost over lifespan	Lower upfront (capital constructional costs), high repair and/or replacement costs	Higher upfront construction costs (approximately 5% to15% higher with isolation systems). Considerably lower lifecycle cost in reduced damage and downtime, and the intangible economic savings of lower morbidity and mortality following earthquakes.

Existing hospitals can be retrofitted with base isolation technology but this may be a more costly endeavour than new-built hospitals with base isolation systems.

Design Considerations

The flow chart below outlines the design considerations when considering and selecting base isolation systems for new-build or retrofitting of existing hospitals. These design considerations range from conceptual design to determine feasibility of base isolation based on the ground conditions, the building structure and seismic history, through preliminary design to detailed design with protection of non-structural and auxiliary services, and maintenance in mind.

Ministry of Health decision-makers in countries with seismic risk should always include feasibility checks of base isolation systems in hospitals in the Terms of Reference to Design Teams.

Seismic hazard assessment

Ground motion intensity - Base isolation is most effective on structures with short fundamental periods subjected to strong ground shaking.

Soil conditions - Soft soils amplify low-frequency motions, hence it may increase the displacement of the isolators.

Maximum considered earthquake (MCE) - Displacement of MCE must be evaluated.

Building characteristics

Mass and weight - More effective on moderate-to-heavy weights and stiff upper structures, which is typical for hospital structures.

Height - Low-to-mid-rise buildings are best. Very tall, flexible towers are less suitabled as they have long periods.

Occupancy importance - Hospitals and other critical infrastructure benefit the most.

Isolation system selection

Elastomeric bearings (HDRB and LRB) - Good for moderate displacements and are low maintenance.

Sliding bearings (FPB, double concave FPS) - Better for heavy structures and large displacement demands.

Displacement demand

Isolation increases displacement at the base of the building. Design displacement on the design and MCE need to be checked.

Include seismic gaps (moats) around the structure to prevent pounding against other buildings and adjacent ground.

Re-centering & Residual Displacement

Isolators must return to their original position after ground shaking.

Elastomeric bearings have stronger self-centering than sliding systems.

Sliding systems need to check serviceability. There may be residual offsets.

Vertifical load & Uplift

Bearings (isolators) must carry full dead + live loads. Check for heavy equipment load in hospitals.

Check against uplift, especially in asymmetric or irregular buildings.

Interaction with superstructure

Base isolation reduces acceleration but increases displacements. Check for: expansion joints, stair and ramps which may need sliding and flexible details and Utility lines (electrical, water, oxygen) which must have flexible connections to accommodate isolators displacement.

Non-structural components

Major benefit is protection to non-structural systems.

Detail anchorage and systems to safety transfer loads from equipment and non-structural systems.

Maintenance and inspection

Elastomeric bearings - check for aging, ozone cracking (surface cracking from degradation of the rubber) and bulging.

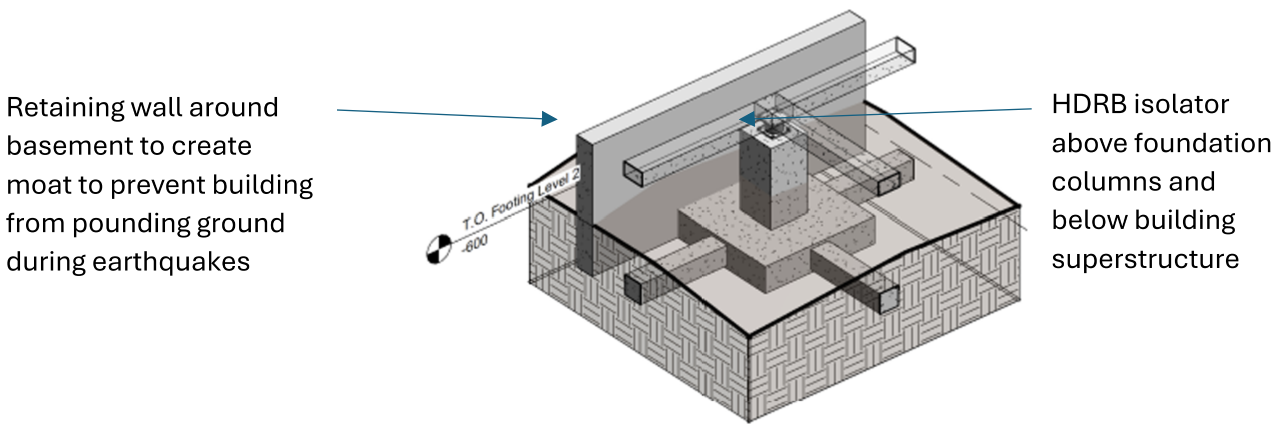
Sliding bearings - inspect lubrication, wear and surface corrosion.

All isolators must be accessible for periodic visual inspections.

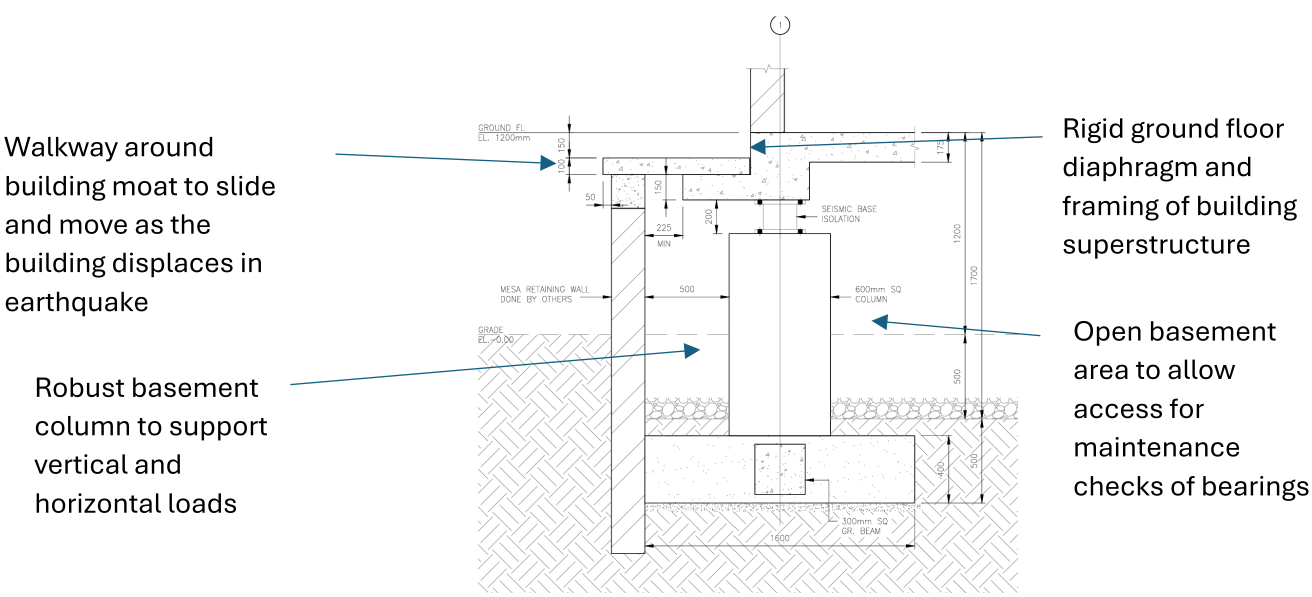
Other important considerations in the design of isolator bearings include:

- The guaranteed performance of the bearings based on production testing standards from the manufacturer and prototypes, if required.
- Installation and tolerances - The manufacturer of the isolators should have technical specifications and tolerances for the installation and should include for supervision during the installation process to ensure warranty and quality control in the installation.
- The long-term monitoring and maintenance requirements of the bearings:
  - Some isolators, based on the materials, may not be suitable for certain environmental conditions such as extreme temperatures. Additionally, HDRB isolators, for example, can have a lifespan of 30-50 years, but can match a building's lifespan (50-100 years) with proper design and protection.
  - Protecting isolators from sunlight, water, ozone and rodents extends life span.
  - ASCE 7 and Eurocode 8 codes require designers to check that isolators can sustain performance goals or the design life of the structure, or else plan for future replacement.
- Post-earthquake inspection of bearings to check if isolators need to be replaced or reset especially following a strong event which exceeds the elastic demand of the isolators.

[6]Illustrations of HDRB isolator in RC frame building.

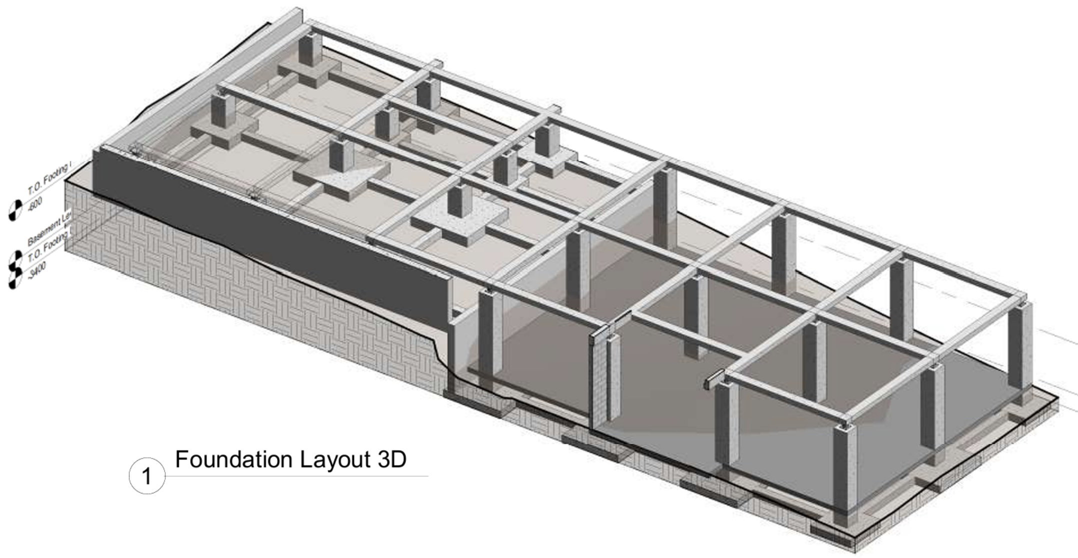


3D model of base isolator bearing on basement column



[6] Illustrations courtesy Allahar Associates Limited.

Example of HRDB isolator in RC building



Base Isolated Hospital Example

Mexico City

On 19 September 1985 at 7:17am an 8.0 moment magnitude earthquake occurred 350km west of Mexico City. The ground shook for almost 3 minutes and resulted in approximately US $4 Billion in losses.

About 3,500 buildings had collapsed or were seriously damaged of which 880 were completely destroyed.

Hospital Juarez was one of the oldest hospital institutions of Mexico, founded in 1847. The tower was built in 1970, 12-storeys tall with an in-patient capacity of 536 beds. It was at 80% capacity when the earthquake struck and the steel frame structure collapsed within minutes of the event. 561 bodies were found (188 were never identified) of which 266 were identified as hospital worker and 44 were medical residents.

Following the 1985 Mexico Earthquake, the ministers of health decided that having adequate response to such events was not enough and it was decided to implement **mitigation measures** to prevent the collapse of health infrastructure.

Of the estimated 18,000 hospitals in the Region of the Americas, approximately 67% are located in high-risk areas.

PAHO Safe and Smart Hospitals

PAHO Safe Hospitals Initiative, and subsequent, Smart Hospitals was born out of the tragic losses of the 1985 Mexico earthquake.

The objectives of Safe and Smart Hospitals are to enable operational protection, that is, to allow hospitals to continue to function and provide appropriate and sustained healthcare services during and following emergencies and disasters.

- To Protect lives
- Protect investment i.e. the physical integrity of hospital buildings, equipment and critical systems
- And to Make hospitals safe and resilient to hazards

Tláhuac General Hospital

[7] Tláhuac General Hospital, located south of Mexico City, Mexico, is the first public hospital to incorporate seismic base isolation system in Mexico and is certified as a "Safe Hospital" in accordance with the National Evaluation, Diagnosis and Certification Committee of the Safe Hospitals Program. Tláhuac General Hospital is a 250-bed facility spread over 35,000 square meters.

[7] Sacyr S.A. 2025, Health Infrastructures, "Tláhuac General Hospital: the most important hospital infrastructure in Mexico City", https://sacyr.com/en/

[8]Photo 1 - Tláhuac General Hospital, Mexico City, Mexico

It is located in the former lakebed area of Mexico City which is characterised by soft clay soils with a high water table. Moderate earthquakes in this area correspond to strong earthquakes due to the soil type. The soft soils with shear wave velocities, Vs < 100m/s have very low natural frequencies resulting in soft soil periods of 2-3 seconds or longer. This can amplify long-period seismic waves. Although this can have significant soil damping, it still results in large lateral displacements of buildings.

The base isolation and damping system of the Tláhuac General Hospital was designed to ensure that the displacement was limited to 400mm down from the expected 1m to 1.2m seismic displacement.

[8] Engineering and Sales in Design and Construction, Mexico City Hospital, https://esdescon.az/en/projects/175-mexico-city-hospital.html

[9]Photo 2 - One of the 243 elastomeric bearings (isolators), 850mm diameter supplied by MAURER

Special Considerations

Whilst base isolation can be used in soft soil regions like Mexico City as highlighted by Tláhuac General Hospital, it is a custom-designed building. The resonance, displacement and damping must be very carefully analysed and designed. The base isolation systems are often required in combination with deep foundations and additional damping mechanisms.

[9] Engineering and Sales in Design and Construction, Mexico City Hospital, https://esdescon.az/en/projects/175-mexico-city-hospital.html