HOSPITAL SAFETY AND EARTHQUAKES: DO WE MATCH GLOBAL STANDARDS?

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INTRODUCTION

As this Article goes to print, Toll in the most unfortunate, recent Turkey and Syria Earthquakes has crossed 33000 and no. of missing/injured is mounting. Loss of large no of Buildings and key infrastructure remains to be assessed, while the rescue operations are on, on a big scale, assisted by multi country teams. All of this is a grim reminder that it's poorly designed and poorly constructed buildings that kill people and not the Earthquakes.

It thus becomes critically important for us to review how safe is our built environment against a likelihood of a serious earthquake, especially our healthcare facilities to assist in any post-disaster rehabilitation and recovery. India is located in a seismically active zone and almost 66% of it is prone to earthquakes. Bureau of Indian Standards (BIS) and National Building Code (NBC) provide guidelines for earthquake resistant design of buildings in India, and the objective of this article is to look at the provisions of the current Codes and see how far away we are from global standards for earthquake-resistant design of hospitals.

In National Building Code of India (NBC) and BIS-1893 (Part-1)-2016 guidelines for the design and construction of buildings are general and not specific for hospitals, although the last revision of the Code enhances the Earthquake Base Shear by 50% for hospitals, by suggesting an Importance Factor of 1.5. However, it does not provide exhaustive or special recommendations for seismic design, detailing and construction practices specific to Hospitals including the design/anchorage of non-structural elements.

Besides, in many parts of India, these guidelines may not be strictly followed and enforcement of BIS codes maybe lax, as the BIS Codes are recommendatory and need to be formally adopted by States to make them mandatory. In addition, BIS Codes do not carry any recommendations for ensuring Compliance to revised Code provisions in a given time frame, thus rendering a large no of buildings Non-Compliant. This may make hospitals more vulnerable to collapse during an earthquake, putting patients and staff at risk, as unfortunately happened during the Nepal Earthquakes of 2015.

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As a result of these earthquakes, 446 public health facilities (including five hospitals) and 16 private hospitals were completely destroyed, and 765 health facilities were partially damaged; 84% of completely destroyed facilities were located in the 14 districts most affected by the crisis, resulting in a severe inability to treat the injured.

It is thus, vitally important that hospitals are designed and constructed according to the latest seismic safety standards, and that regular structural audits, retrofitting and maintenance are carried out to ensure their continued safety.

NBC recommends a full scale structural safety audit and retrofitting of all important public buildings, every 3 to 5 years, in its Chapter 2 titled Administration. It clearly recommends that authorities, lacking in adequate technical manpower, may seek assistance from experienced structural engineering professionals and allow continued operation of buildings only once the retrofitting has been completed satisfactorily. This important provision, if implemented in totality, will ensure the safety and well-being of all important buildings including healthcare facilities.

All stakeholders related to any healthcare facility planning and design must also look at and adopt completely the provisions of Hospital Safety Guidelines by NDMA, published in 2016, giving exhaustive guidelines on choice of Structural systems, analysis, design and detailing of new hospital buildings including the non-structural elements (NSEs). This document also spells out very clear recommendations for immediate Audit and strengthening of existing hospitals in India.

GUIDELINES FOR HOSPITAL BUILDINGS AS PER NDMA (HOSPITAL SAFETY)

SALIENT FEATURES

In a hospital building two type of elements are there a) Structural Elements (SEs) b) Non Structural Elements (NSEs). Structural elements are components of buildings, which resist the loads imposed by external load effect and support all Non Structural Elements and NSEs do not resist the loads imposed by external load effect, but are supported by SEs of building; they fulfill the necessary architectural and functional requirements.

Building units of a Hospital campus shall be classified under two groups a) Critical unit of hospital buildings b) Other units of hospital buildings. Critical units of building and structures (SEs and NSEs) provide medical services essential in the immediate aftermath of disasters and other unit of building and structures (SEs & NSEs) that provide all the other service that may not be required in the immediate aftermath of disasters.

No damage is permitted in SEs and NSEs of hospital building when subjected to load other than earthquake. But under the action of earthquake effects two cases arise for SEs and NSEs.

Critical Units		Other Units	
SEs	NSEs	SEs	NSEs
Structural damage commensurate with Immediate Occupancy (IO) performance level is permitted.	Structural damage commensurate with Life Safety (LS) performance level is permitted.	Structural damage commensurate with Immediate Use (IU) performance level is permitted.	Structural damage commensurate with Dysfunctional State (DS) performance level is permitted.

Four aspects shall be addressed to ensure safety of SEs and NSEs of Hospital Buildings:

1. In New Buildings
   (i) Structural Design and Construction
2. In Existing Buildings
   (i) Pre-Disaster Safety Assessment
   (ii) Retrofitting
   (iii) Post-Disaster Damage Assessment

Presently very few documents are available worldwide for architects and engineers to undertake the above activities.

DESIGN STANDARDS

Structural Elements (SEs) of all Critical Units and Other Units of the new Health Facilities shall comply with requirements of NDMA (Hospital Safety) Guidelines in addition to all relevant existing national standards and guidelines laid down by various statutory bodies, non-statutory bodies as well as client owner of health facility. The latest versions of national documents currently in use are:

1. New Hospitals: NBC, IS:875, IS:1893(1), IS:1893(4), IS:456, IS:800, IS:13920, GSDMA Guidelines, IPHS and
2. Existing Hospitals: NBC 2007, IS:875, IS:1893(1), IS:456, IS:800, IS:1905, IS:13920, IS:13935, IS:15988 and GSDMA Guidelines.

STRUCTURAL ELEMENTS

Structural elements of critical units are designed for extreme load effects which are given in this section beyond those specified in the relevant national standards.

New Health Facilities

A new health facility means:

1. A new construction and
2. A reconstruction of an existing facility at the same site or new site.

a) Site Selection

The following sites shall be prohibited for locating a hospital:

- Liquefiable ground;
- Hill slopes (Stable or unstable) or land adjoining hill slopes known to have rolling debris; (whether sloped or flat)
- Flood or tsunami prone areas;
- Adjoining unsafe buildings and structures;
- Poor accessibility in post-disaster situations.

b) Structural Systems

Material - Structural Elements of all new hospital structures shall be made of Reinforced Concrete and/or Structural Steel, except for structures in seismic zone II, where Reinforced Masonry may be used.

Use of Structural Walls - The structural system of new hospital buildings shall NOT be Moment Resisting Frames alone. It should Structural Walls in each of the two mutually perpendicular plan directions of the building in addition to Moment Resisting Frames.

- The structural system of Moment Resisting Frames with Structural Walls shall be designed as a DUAL SYSTEM (as defined in IS:1893 (Part 1).
- The Structural Walls shall be made of

Reinforced Concrete (RC) and provided in select bays running through the full height of the building, irrespective of choice of material of the basic structural system adopted for the hospital, namely RC or Structural Steel.

- The total cross-sectional area of all RC Structural Walls shall be at least 4% of the plinth area of the building, along each of the two mutually perpendicular principal plan directions.
- RC Structural Walls shall be designed in accordance with IS:13920 or specialist literature more stringent than IS:13920.
- At each joint of Moment Resisting Frames, the design moment capacity of column section shall be at least 2 times design moment capacity of beam section.

Base Isolation Systems - Base Isolation System is an expensive technology option though effective to counter ill effects of strong earthquake shaking in new hospital buildings. Hence, Base Isolation System may be adopted in important hospitals in seismic zones IV and V. But, this shall be adopted only when safety of such hospital buildings is established by

- Analytical Methods, through nonlinear pushover analyses and nonlinear time history analyses under a suite of appropriate earthquake ground motions and
- Full-scale experimental testing of base isolation devices demonstrating that they are capable of resisting expected strong earthquake shaking.

Prohibited Structural Systems - The following structural systems shall be prohibited for use in new hospitals:

- Flat Slab buildings, with or without central core;
- Prestressed floor systems;
- Precast constructions (with natural or man-made materials), in part or whole of the structure and
- Pre-engineered structures, in part or whole of the structure.

c) Structural Configuration

- Regular Structural Configurations: All new hospital buildings shall have regular structural configuration only. Buildings shall be deemed to be regular when they meet requirements laid out in Clause 7.1 of the Indian Seismic Code IS:1893 (Part 1). Floating and setback columns shall not be allowed in buildings.
- Structural Configurations Prohibited: Structural configurations with open ground storeys or flexible or weak storeys at any other level shall be prohibited in hospital buildings.

“Base Isolation System may be adopted in important hospitals in seismic zones IV and V.”

(d) Structural Analysis

- Multiple 3D models shall be considered in the analyses of Critical Units of Hospital Buildings to estimate the effects on strength and deformation demands of these Critical Units of Hospital Buildings.
- Individual footing shall be checked for uplift actions under the action of extreme load effects.

(e) Structural Design

SEs of Critical Units of Hospital Buildings shall be designed to resist elastically the expected load actions on them, including those due to earthquake effects. Hence, the design lateral earthquake forces prescribed in this guideline are much larger than those currently employed in design of buildings (including hospitals), to meet the requirement of immediate use of the hospital building structure and fully functional performance of the NSEs within the hospital building. Here, “designed to resist elastically” shall imply that the stress-resultant demands (namely P, V, M and T) on each structural element is less than its associated nominal capacities (as defined by IS:456 and IS:800 for structural elements made of RC and Structural Steel, respectively).

The design horizontal acceleration coefficient Ah given in Clause 6.4.2 of IS:1893 (1)-2016 for design of SEs shall be replaced by

$$A_h = \frac{ZI}{R}\left(\frac{S_a}{g}\right) \qquad (1)$$

Where, Z is the Seismic Zone Factor, I the Importance Factor, Sa/g the Design Acceleration Spectrum for three different soil conditions, and R the Response Reduction Factor, all as defined in IS:1893 (1)-2016.

Effects of vertical earthquake ground shaking also shall be considered in the design of SEs.

As per IS1893 (4)-2015 the Hospital Buildings are kept under Category 2 for which Importance factor is 1.5

Existing Health Facilities

An existing health facility means:

- All existing health facilities that do not meet the standards mentioned in this guideline,
- A reconstruction of an existing facility at the same site or new site, and
- An existing commercial, office or residential buildings designed and built for other functional use, but now intended to be used as a hospital facility.

(a) Building Configuration
The building structure of retrofitted hospitals shall meet the criterion specified in this section.

Originally REGULAR or IRREGULAR Buildings: Buildings shall deemed to be REGULAR or IRREGULAR when they meet requirements laid out in the current Indian Seismic Code IS:1893 (Part 1)-2016). The retrofitted regular or irregular building shall meet the following criterion:

- Structural analysis shall be performed as given in IS:13935 or IS:15988 for seismic safety assessment of retrofitted Regular Buildings, to assess (i) the stress resultant demands (of axial load, shear forces and bending moments) on different structural elements in the existing building, and (ii) the lateral drift demand on the different storeys of the building.
- These stress resultants demands imposed by the level of shaking considered shall not exceed the design capacity of any structural element of the existing building with the considered retrofit scheme.
- The storey lateral drift demand in the existing building for regular building shall not exceed 0.4% of the height of the storey and 0.35% of the height of storey for irregular building using un-cracked section properties.

(b) Structural Design
Making existing Critical Units of Hospital Buildings meet requirements laid down for new hospitals in this Guideline can be difficult – it can be too stringent to meet the specifications corresponding to new buildings, or even too expensive do so. When existing deficient Critical Units of Hospital Buildings are to be retrofitted, they shall be designed to resist the effects of earthquake shaking given by the design horizontal acceleration coefficient A_h given in Clause 6.4.2 of IS:1893 (1)-2016 for design of SEs given by:

$$A_h = \frac{ZI}{2R}\left(\frac{S_a}{g}\right) \qquad (2)$$

where, Z is the Seismic Zone Factor, I the Importance Factor, Sa/g the Design Acceleration Spectrum for three different soil conditions, and R the Response Reduction Factor, all as defined in IS:1893 (1)-2016.

Non Structural Elements

NSEs of all new hospital and all existing hospital building shall comply with all relevant existing national standards and NDMA Guidelines.

Design Strategy - NSEs shall be classified into three types depending on their earthquake behaviour, namely:

a) Acceleration-sensitive NSEs: The lateral inertia forces generated in these NSEs during earthquake shaking cause their sliding or toppling to the level of their base or lower.

b) Deformation-sensitive NSEs: The relative lateral deformation in these NSE spanning between two SEs (e.g., a pipeline passing between two parts of a building with a separation joint in between) or between an SE and a point outside building (e.g. an electric cable between the building and ground/pole outside the building), causes them move or swing by large amounts in translation and rotation under inelastic deformations of SEs imposed on them during earthquake shaking; and

c) Acceleration-and-Deformation-sensitive NSEs: Both of the conditions described in (a) and (b) above are valid.

Non Structural Elements Prohibited:
The following systems shall be prohibited for use as NSEs and its connections to the SEs in new hospitals:

- False ceilings hung from soffit of RC roof or floor slabs with anchor fasteners embedded in concrete portion of RC slabs; when false ceilings are required from medical safety point of view, exceptions shall be allowed subject to requirements given in NDMA Guidelines.
- Tiles pasted on unreinforced load-bearing masonry walls, unreinforced masonry infill walls or RC walls.
- Glass façade made of stone, ceramic, glass, etc.; when glass facades are required from medical safety point of view, exceptions shall be allowed subject to requirements given in NDMA Guidelines.
- Any NSE nailed to or supported by the Unreinforced Masonry Infill walls made of any material.

Design Guidelines –
Acceleration Sensitive NSEs

The design lateral force Fp for the design of acceleration-sensitive NSEs may be taken as:

$$F_p = Z\left(1+\frac{x}{h}\right)\frac{a_p}{R_p}I_pW_p \qquad (3)$$

Where, Z is the Seismic Zone Factor (as defined in IS:1893 (Part 1)), I_p the Importance Factor of the NSEs (Table 1), R_p the Component Response Modification Factor (Table 2), a_p the Component Amplification Factor (Table 2), Wp the Weight of the NSE, x the height of point of attachment of the NSE above top of the foundation of the building, and h the overall height of the building.

Table 1- Proposed Importance Factors I_p of NSEs

NSE	I_p
Component containing hazardous contents	2.5
Life safety component required to function after an earthquake (e.g., fire protection sprinklers system)	2.5
Stroage racks in structures open to public	2.5
All other components	2.0

Table 2- Coefficient a_p and R_p of Architectural, Mechanical and Electrical NSEs

S No.	Item	a_p	R_p
1.	**Architectural Component or Element**		
	Interior Non-structural Walls and Partitions		
	Plain (unreinforced) masonry walls	1	1.5
	All other walls and partitions	1	1.5
	Cantilever Elements (Unbraced or braced to structural frame below its center of mass)		
	Parapets and cantilever interior non-structural walls	2.5	2.5
	Chimneys and stacks where laterally supported by structures	2.5	2.5

	Cantilever Elements (Braced to structural frame above its center of mass) Parapets Chimneys and stacks Exterior non-structural walls	 1 1 1	 2.5 2.5 2.5
	Exterior Non-structural Wall Elements and Connections Wall element Body of wall panel connection Fasteners of the connecting system	 1 1 1.25	 2.5 2.5 1
	Veneer High deformability elements and attachments Low deformability and attachments	 1 1	 2.5 1.5
	Penthouses (except when framed by and extension of the building frame)	2.5	3.5
	Ceilings All	 1	 2.5
	Cabinets Storage cabinets and laboratory equipment	 1	 2.5
	Access Floors Special access floors All other	 1 1	 2.5 1.5
	Appendages and Ornamentations	2.5	2.5
	Signs and Billboards	2.5	2.5
	Other Rigid Components High deformability elements and attachments Limited deformability elements and attachments Low deformability elements and attachments	 1 1 1	 3.5 2.5 1.5
	Other flexible Components High deformability elements and attachments Limited deformability elements and attachments Low deformability elements and attachments	 2.5 2.5 2.5	 3.5 2.5 1.5
2.	**Mechanical and Electrical Component/Element**		
	General Mechanical Boilers and furnaces Pressure vessels on skirts and free-standing Stacks Cantilevered chimneys Others	 1 2.5 2.5 2.5 1	 2.5 2.5 2.5 2.5 2.5
	Manufacturing and Process Machinery General Conveyors (non-personnel)	 1 2.5	 2.5 2.5
	Piping Systems High deformability elements and attachments Limited deformability elements and attachments Low deformability elements and attachments	 1 1 1	 2.5 2.5 1.5
	HVAC System Equipment Vibration isolated Non-vibration isolated Mounted in-line with ductwork Other	 2.5 1 1 1	 2.5 2.5 2.5 2.5

	Elevator Components	1	2.5
	Escalator Components	1	2.5
	Trussed Towers (free-standing or guyed)	2.5	2.5
	General Electrical Distributed systems (bus ducts, conduit, cable tray) Equipment	 2.5 1	 5 1.5
	Lighting Fixtures	1	1.5

Design Guidelines

Displacement Sensitive NSEs

The NSE can be supported between two levels of the same building, or between two different buildings, between a building and the ground, or between building and another system (like an electric pole or communication antenna tower). The design relative displacement D shall be estimated as below:

i) Design HORIZONTAL and VERTICAL relative displacements DX and DY, respectively, between two levels of the same building (Building A), one at height hz1 and other at height hz2 from base of the building at which the NSE is supported consecutively, shall be estimated as:

$$D_X = 1.2\left(\delta^{AX}_{z1} - \delta^{AX}_{z2}\right)$$

$$D_Y = 1.2\left(\delta^{AY}_{z1} - \delta^{AY}_{z2}\right) \quad (4)$$

Where,

$$\left(\delta^{AX}_{z1} \text{ and } \delta^{AX}_{z2}\right) \;\&\; \left(\delta^{AY}_{z1} \text{ and } \delta^{AY}_{z2}\right) \quad (5)$$

These are the design HORIZONTAL and VERTICAL displacements, respectively, at levels z1 and z2 of the building A (at heights hz1 and hz2 from the base of the building) under the application of the load effects.

ii) HORIZONTAL and VERTICAL relative displacements DX and DY, respectively, between two levels on two adjoining buildings or two adjoining parts of the same building, one on the first building (Building A) at height hz1 from its base and other on the second building (Building B) at height hz2 from its base, at which the NSE is supported consecutively, shall be estimated as:

$$D_X = \left|\delta^{AX}_{z1}\right| + \left|\delta^{BX}_{z2}\right|,$$

$$D_Y = \left|\delta^{AY}_{z1}\right| + \left|\delta^{BY}_{z2}\right|, \quad (6)$$

Where,

$$\left(\delta^{AX}_{z1} \text{ and } \delta^{AX}_{z2}\right) \text{ and } \left(\delta^{AY}_{z1} \text{ and } \delta^{AY}_{z2}\right) \quad (7)$$

These are the design HORIZONTAL and VERTICAL displacements, respectively, at level z1 (height hz1) of building A and at level z2 (height hz2) of building B, respectively, at which the two ends of the NSE are supported.

CONCLUSION

Safety of all critical infrastructures in India against Earthquakes needs to be ensured by enforcing strict implementation of the design guidelines by NDMA and relevant BIS Codes. A Safe design has to start with correct site selection, following regular geometry as well as the design performance levels as stipulated in the Guidelines. However, the Guidelines and BIS Codes for Hospital Design must be upgraded further to match Global Safety standards of Operational Category as adopted globally for all critical units.