Guru Tegh Bahadur Hospital

A Summary of the Seismic Evaluation and Retrofit Process

Delhi Earthquake Safety Initiative for Lifeline Buildings

Prepared by:

GeoHazards International

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Executive Summary

Guru Tegh Bahadur (GTB) Hospital is a large teaching hospital in the Trans-Yamuna area of Northeast Delhi. The hospital is under tremendous pressure even under normal operating conditions: designed as a 1000-bed hospital, GTB now has 1500 beds. In addition, the medical staff treats up to 5500 outpatients per day. If the earthquakes that the project engineers used as a basis for design should strike the city, then they will cause tremendous death and destruction in the densely populated and poorly built buildings in the surrounding area. The hospital will need to treat the injured and therefore, doctors should be able to use its buildings shortly after the design earthquake strikes.

Delhi PWD, the hospital, and the project's peer review panel determined that hospital buildings should satisfy the immediate occupancy performance level for the Design Basis Earthquake (a major earthquake), and the life safety performance level for the Maximum Considered Earthquake (the largest earthquake that scientists believe is likely to happen). As a result of this project, Delhi PWD engineers designed GTB's new building with base isolation technology, so that it would also have immediate occupancy performance under very large earthquakes. The immediate occupancy performance level means that only very minor structural damage will occur; however, meeting this standard will not translate to continued operation, unless the building's equipment and mechanical systems are also anchored. The life safety performance level means that the lives of the people inside the building will be protected, but that the building will be extensively damaged, perhaps beyond repair.

Though the site has many buildings, this project focused on the eight-storey Ward Block and its connecting corridors and on the physical plant where the major mechanical equipment is located. Delhi PWD gathered information, conducted geotechnical investigations, and assessed the building's condition. The building was built in the 1980's by the Central Public Works Department (CPWD), so the original structural drawings remain available. Based on the geotechnical data collected, Delhi PWD determined that liquefaction is unlikely.

Structural Design and Engineering Consultants Pvt. Ltd. conducted linear analyses of the building, and Indian Institute of Technology (IIT) Roorkee conducted nonlinear static pushover analyses of the building and corridor structures. Linear code analyses showed generally overstressed conditions in the frame, but subsequent nonlinear analyses, which took into account the building's significant overstrength and true vibration properties, showed that the building's frame achieved immediate occupancy performance for the Maximum Considered Earthquake.

The brick partitions would fall out into the rooms and could injure patients and staff, so Delhi PWD, IIT Roorkee, and the peer review panel developed a solution for bracing the partitions to keep them from falling. The partition bracing was being designed and costed at the time that this report was written. Delhi PWD plans to install the bracing one room at a time, in order to reduce disruptions to the continuously occupied hospital.The major mechanical equipment in the physical plant that the hospital needs to keep operating will be anchored and braced.

Once these retrofit measures are in place, the medical staff should be able to use the ward block, with minimal clean-up, shortly after an earthquake.

Project Team Members

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Introduction

Guru Tegh Bahadur (GTB) Hospital is a large teaching hospital, which is located in the Trans-Yamuna area of Northeast Delhi. The hospital is financed and administered by the Delhi government and is affiliated with the University College of Medical Sciences at Delhi University. The hospital is under tremendous pressure under normal operating conditions, and delivers healthcare to a large population of economically disadvantaged residents of East Delhi and neighboring Uttar Pradesh state. As a government hospital, GTB provides free and low-cost medical care to the poor, and its services are in great demand. It was designed as a 1000-bed hospital, but serves up to 1500 inpatients and 4500 outpatients per day.

A major earthquake will flood the hospital with casualties. The surrounding area is very densely populated, and many of the buildings are poorly built of brick and non-ductile concrete. The area's soft soils will amplify earthquake shaking. As a result, the buildings surrounding the hospital will experience heavy damage during a major earthquake, and the hospital will be urgently needed to treat the injured. In addition, the approaches of the major bridges over the Yamuna River may be damaged, rendering them impassible and Trans-Yamuna cut off from the rest of the city.

GTB Hospital was seismically assessed as part of the Delhi Earthquake Safety Initiative for Lifeline Buildings. This project was jointly funded by the Government of the National Capital Territory of Delhi and the United States Agency for International Development. GeoHazards International (GHI) formed a peer review panel of experts from India and the United States to guide Delhi PWD engineers through the seismic assessment and retrofit of five groups of important existing buildings, and to build their capacity to retrofit additional buildings in the future.

Project participants originally planned to assess five buildings at the hospital—the Ward Block, the Operating Theater (OT) Block, the Casualty Ward, the blood bank, and the physical plant. Due to time and workload constraints, project participants only took the Ward Block, its corridors, and the physical plant through the seismic assessment and retrofit process.

In addition to housing in-patients, the Ward Block has beds for pre- and post-operative patients and has housed the obstetrics and pediatrics departments. These two departments will move to a newly constructed, base-isolated building designed by Delhi PWD as a result of this project.

The Delhi PWD began the seismic assessment and retrofit process by gathering information on the building's design, construction, and current condition, and by conducting initial walk-through inspections. Because CPWD's Central Design Office designed the building, the original structural drawings are available. The peer review panel visited the sites with Delhi PWD engineers in April, 2005. Due to a heavy workload and a lack of internal analysis capacity, Delhi PWD contracted out both the linear and nonlinear analyses of the building, to Structural Design and Engineering Consultants (SDEC) Pvt. Ltd. and IIT Roorkee, respectively. The peer review panel reviewed the modeling assumptions, analysis methods, and results.

The nonlinear analyses showed that the building's concrete frame was capable of immediate occupancy performance in the design basis earthquake, but the masonry partitions would collapse. At the time this report was written, design drawing and cost estimates for partition bracing and mechanical equipment anchoring were underway. Retrofit of the masonry partitions will take place incrementally, in order to minimize disruption.

Building Description

The hospital campus is located in Shahdra in Delhi's North-East District, which is some distance east of the Yamuna River. Figure 1 shows the hospital's location with respect to the remainder of Delhi, the Uttar Pradesh border, and the Yamuna River.

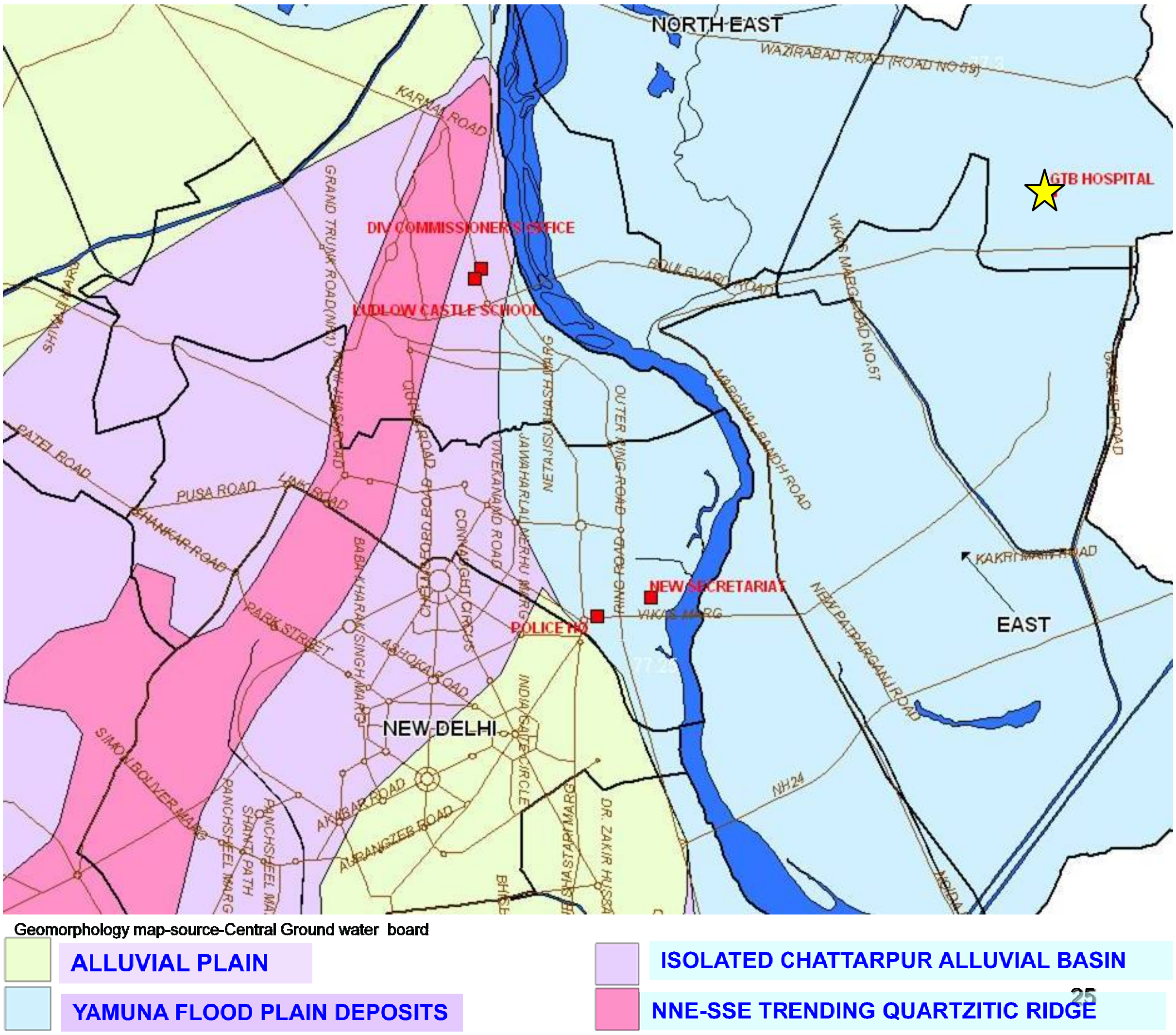

Figure 1. Location of hospital (yellow star) and other project buildings (red squares)

Figure 2 shows a portion of the campus, with the Casualty Ward, Operation Theater Block, Ward Block, and blood bank building shown left to right. A bulk medical gas tank is located at center left.

Figure 2. Elevation view of Casualty Ward, OT Block, and Ward Block (left to right).

The Ward Block, built in 1982 by CPWD, is the large cream-colored building in Figure 2 above. It houses over 750 patient beds, despite being initially designed for 500 beds. The eight storey (ground plus seven) building is 27 m (88 ft) tall, and has a total floor area of 18,000 sq m (200,000 sq ft). The building is connected to the eight storey OT Block on its east side by an eight storey reinforced concrete corridor structure. On the west side, there is a two storey kitchen building, separated from the Ward Block by a 50 mm (2 in) expansion joint. There are no adjacent buildings on the north or south sides of the Ward Block.

The Ward Block consists of four identical blocks separated by expansion joints. Two blocks are located on the south side of a central courtyard, and two blocks are located on the north side, as shown in Figure 3. The four blocks are connected by eight storey corridor structures on the east and west sides of the courtyard, and by a two storey corridor structure across the center of the courtyard. Figure 4 shows the interior and exterior views of the corridors. Figure 5 shows the two storey corridor and the typically crowded conditions in the courtyard.

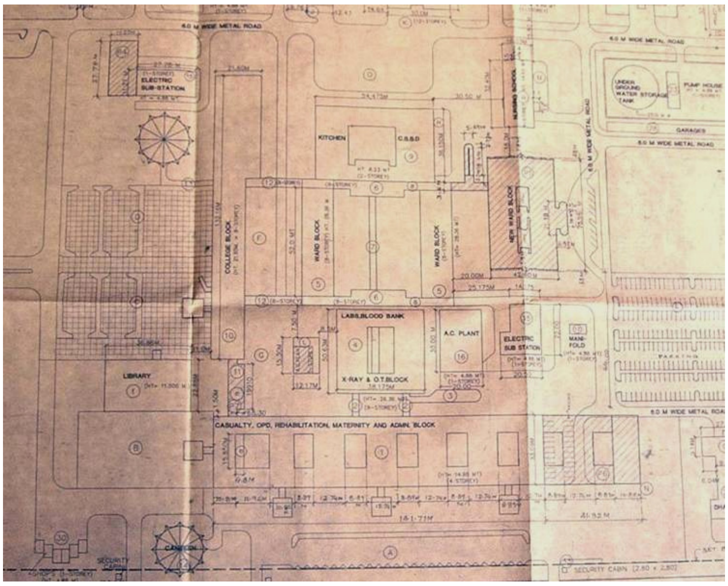

Figure 3. Plan view showing the Ward Block and corridors (located in center above fold)

Figure 4. View of eight storey and two storey corridors from courtyard; exterior view of north-west corner showing corridor-block connection and adjacent blood bank building

Figure 5. Two storey corridor across the central courtyard (left); courtyard occupied by relatives of patients (right)

The building has a reinforced concrete frame system with some infill walls. Ductile details such as 135° hooks were not provided, but the frame does have closely spaced column ties near the joints. The original design did not consider the impact of masonry infill walls on building behavior. Fortunately, there are few infill walls - double wythe (230 mm or 9 in thick) brick walls are found in the staircases and a few other isolated locations. However, every room has single wythe (4.5 in thick) brick partitions.

The foundation consists of a 1.05 m (40 in) raft constructed at a depth of 2.1 m (7 ft) with M20 (2250 psi) concrete. The column longitudinal steel is adequately developed into the raft. External columns are connected with a grade beam at ground level, and the space between the raft and grade beams is filled with 380 mm (15 in) thick stone masonry in 1:6 cement mortar. Internal columns are connected at the plinth level, which is 45cm (18 in) above grade level. The gap between raft and plinth beams was not backfilled. The columns are 400mm by 600mm (16 in by 24 in) and constructed of M25 (2850 psi) concrete. Column ties are 8mm (3/16 in or #3 bars) at 100mm (4 in) on center 600mm (24 in) above and below the joints. The reinforced concrete beams are typically 300 by 600 mm (12 in by 24 in) or 400 by 600 mm (16 in by 24in) cast with M20 concrete. The floor slabs are only 100 mm (4 in) thick cast with M15 (1700 psi) or M20 concrete, but qualify as rigid diaphragms based on their reinforcement ratio.

The windows have reinforced concrete sill bands spanning between each column. The sill bands project about 760 mm (30 in) and form the top of the storage cupboard for the patient rooms. The floor slab also projects 760 mm (30 in) as a cantilever and functions as the floor of the cupboard. Bricks were laid between the floor slab and sill band to form the back of the cupboard. There are also fins on all external walls, which do not have proper development length to resist any lateral forces. Figure 6 shows the cupboards, fins, and window air coolers. All of these items could fall from the building into the courtyard below during an earthquake.

Figure 6. Elevation views of interior courtyard showing fins, cupboards (wide cream-colored bands) and air coolers (left); inadequately secured air cooler (right)

Delhi PWD conducted a condition assessment and found that there was no major visible deterioration in most of structural members such as columns, beams and slabs. However, a small number of external columns had noticeable cracks and corroded rebar. The machine room columns on the roof and some exterior architectural elements were badly deteriorated, as Figure 7 shows.

Figure 7. Corroded columns at machine room on roof (left); spalled concrete on exterior architectural elements (right)

Site Seismic Hazard

Ground Shaking

The ground shaking hazard for the purposes of engineering design was defined by the seismic zoning map and response spectrum given in *Indian Standard 1893 (Part 1):2002 Criteria for Earthquake Resistant Design of Structures*. For Delhi, the Maximum Considered Earthquake (MCE) peak ground acceleration (PGA) is 0.24 g. The project did not have the time, political backing, or funding to conduct site-specific hazard analyses. Some existing studies helped panel members to assess, in a very limited sense, whether the code values were appropriate for design. A study of seismic hazard by Iyengar (2000) indicates that acceleration between 0.18 and 0.23 g can be expected at rock level for an earthquake with a 2% probability of exceedance in 50 years (this corresponds to an earthquake with a return period of 2500 years). An older analysis by Khattri (1992) suggests that Delhi will see shaking of on the order of 0.2g from an event with a 10% probability of exceedance in 50 years (this corresponds to an earthquake with a return period of 475 years). Shaking will be stronger at soil sites due to site amplification, and the Indian Meteorological Department is preparing a microzonation map that will quantify the amplification in various areas. The Global Seismic Hazard Assessment Project (GSHAP) map gives a PGA of about 0.14g for Delhi.

However, these probabilistic assessments were made without the benefit of extensive earth science studies, to better define the hazards posed by local seismic sources and the likely size and recurrence interval for Himalayan events. GHI anticipates that current and future studies by earth scientists will lead to better quantification of Delhi's seismic hazard and to revision of the design shaking values. Based on the currently available earth science information and studies discussed above, the peer review panel did not view the code values as unconservative.

Geotechnical Conditions

The building is located in the Trans-Yamuna region, on the thick sediments of the Indo-Gangetic Plain. As Figure 1 shows, the site is underlain by alluvial sediments deposited recently by the Yamuna River. The site is not located near slopes, embankments, or fault traces, so the primary ground failure threat comes from liquefaction.

Delhi PWD conducted geotechnical investigations for the new ward base-isolated block building in 2003-2004, and drilled three boreholes. The investigation found that the N values (determined from standard penetration tests) are about 8-12 and rise to more than 20 below 15 m. The water table is approximately 5 m below the ground level (before monsoon) and is expected to be slightly higher during the monsoon season. The soils are sandy soils of medium stiffness (SM or ML).Based on the data collected, Delhi PWD determined that liquefaction was unlikely.

Design Criteria

The peer review panel recommended the use of a two-level performance criterion for all project buildings. Relations between the performance level, the design earthquakes in the IS 1893 code, and the peak ground acceleration are shown in the tables below. The peer panel attempted to relate the retrofit performance criteria back to the Life Safety performance intended by the IS 1893 code provisions, and decided that recommended criteria for enhanced performance are philosophically equivalent to designing the building to life safety for a larger ground motion.

	Design Basis Earthquake		Maximum Considered Earthquake	
Buildings	Performance Level	PGA (g)	Performance Level	PGA (g)
Hospitals	Immediate Occupancy*	0.12	Life Safety	0.24
Non-hospitals	Life Safety + Damage Control*	0.12	Collapse Prevention	0.24

*These performance criteria are considered to be philosophically equivalent to using I=2.0 for hospitals and I=1.5 for non-hospitals, which give Life Safety performance at 0.24g for hospitals and 0.18g for non-hospitals. Any actual designs using IS 1893 will use 0.24g for hospitals and 0.18g for non-hospitals.

Buildings	PGA (g) for which above criteria correspond to Life Safety using IS 1893
Hospitals	0.24
Non-hospitals	0.18

The Immediate Occupancy performance level means that the building will suffer only very minor structural damage, and can be used with minor cleanup. In order to make the building operational following the earthquake, building utilities, medical gas systems, mechanical equipment, architectural elements, medical equipment, and furnishings need to be anchored or braced in advance to prevent earthquake damage.

Structural Assessment and Analysis

Delhi PWD performed an initial assessment using the ASCE 31 Tier 1 Checklist for Type C-3 buildings (concrete frame with masonry infill walls. SDEC conducted linear analyses of the Ward Block. IIT Roorkee performed eigenvalue and nonlinear static pushover analyses of the Ward Block and its adjacent two-storey and eight-storey corridor structures.

ASCE Tier 1 Checklist

Noncompliant items from the ASCE 31 Tier 1 Checklist included:

- Transfer to shear walls
- Deterioration of concrete

Linear Analysis

Linear analyses by SDEC showed that approximately eight percent of the building's beams and columns would fail. Based on this analysis, the peer panel recommended that Delhi PWD investigate adding shear walls or buttresses to the exterior. SDEC analyzed the building with buttresses, but later nonlinear analyses showed that the building frame would meet the performance criteria without those measures.

Nonlinear Analysis

IIT Roorkee performed numerous nonlinear analyses, which are documented in detail in their report to Delhi PWD entitled "Pushover Analysis of GTB Hospital Ward Block Building" and submitted in November, 2006. IIT Roorkee began by carrying out nonlinear static pushover analyses of a two-dimensional bare frame model. Nonlinear static pushover analyses in both directions were then performed on a three-dimensional model with the pairs of north and south blocks stitched together. Detailed descriptions of the modeling assumptions and analyses can be found in the report by IIT Roorkee mentioned above. Modeling and analytical assumptions common to all the buildings, which were determined by consensus at the third meeting of the peer panel, are listed below:

- Shear walls will be modeled as wide columns
- Masonry infill walls will be modeled as braces with properties of equivalent struts
- Expected material strengths will be used: characteristic strength for concrete, 1.15 times mean Fy for steel
- Masonry material properties will be modeled using test results from IITs
- The IS 1893 parabolic distribution will be used for all buildings, with additional measures to take into account higher modes in the Police Headquarters building
- Foundations will be initially modeled as rigid, with springs added as necessary, with the addition of retrofit measures like shear walls
- The coefficient method from U.S. Federal Emergency Management Agency Report FEMA 440 will be used to determine target displacements
- Both moment and shear hinges will be placed at column ends

Figure 8 shows the deformation in plastic hinges at the MCE target displacement in the transverse direction, obtained by nonlinear static pushover analysis. Figure 9 shows similar results for the longitudinal direction. The legend shows how the hinge colors relate to the FEMA 356/ASCE 41 deformation limits used to determine whether the building meets the performance criteria. The only hinges not pink or blue (the colors signifying IO performance) are the diagonals that represent the brick infill walls in the model, which are green, meaning they are at collapse prevention.

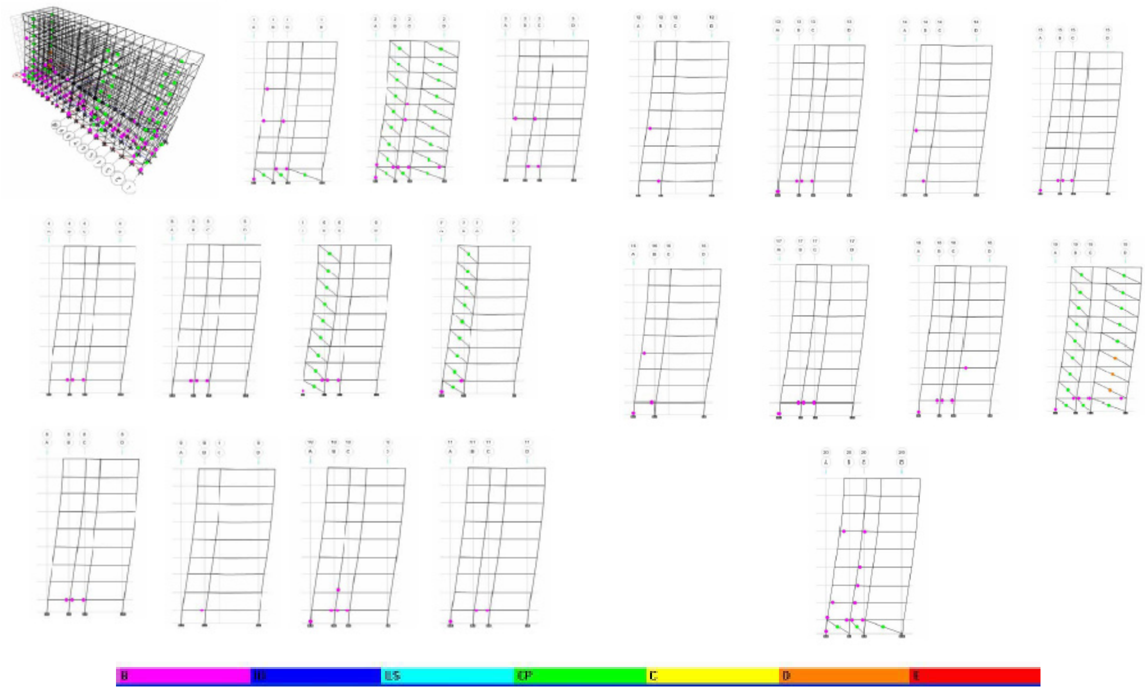

Figure 8. Plastic hinges at the MCE target displacement, X-direction. Pink or blue indicate IO, green indicates CP.

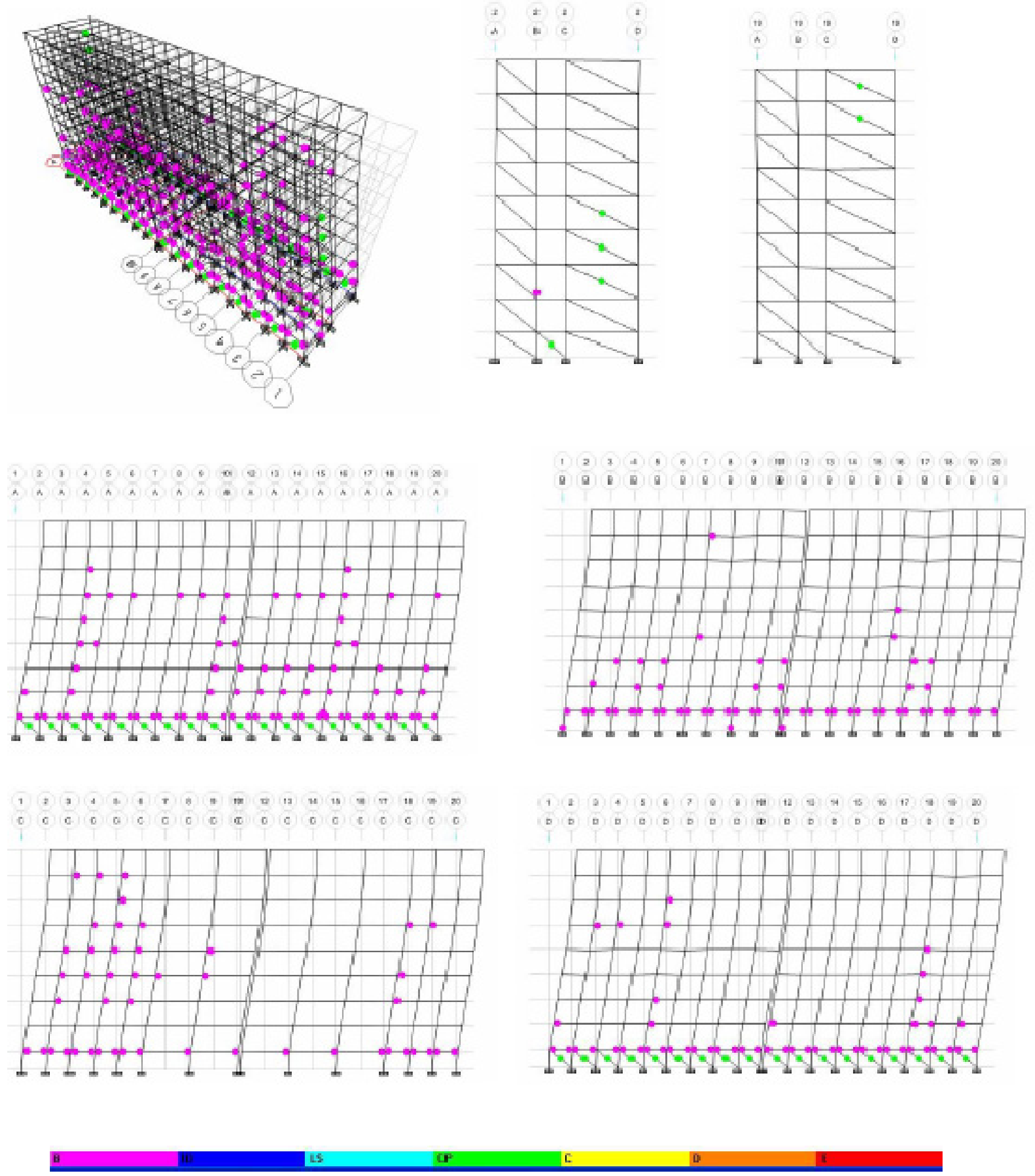

Figure 9. Plastic hinges at the MCE target displacement, Y-direction. Pink or blue indicate IO, green indicates CP.

The nonlinear analysis results in Figure 8 (transverse direction) and Figure 9 (longitudinal direction) showed that when the pairs of blocks were connected together, the building's frame could achieve immediate occupancy performance in both the DBE and the MCE. The infill partitions would collapse, however, and needed to be restrained against out-of-plane failure.

Retrofit Scheme Selection

Recommended Retrofit Scheme

Based on IIT Roorkee's analysis that showed that the Ward Block's concrete frame would meet the performance criteria without retrofit, the recommended measures consist of the following:

- Stitch the pairs of blocks on the north and south sides together to prevent pounding;

- Insert steel channels in each room to brace the brick partitions out-of-plane. The channels can also be used to anchor equipment and furnishings;
- Strengthen the two-storey corridor;
- Place flexible connections on rooftop pipes where they cross expansion joints;
- Anchor and brace major mechanical equipment in the physical plant;

At the time this report was written, Delhi PWD was finalizing the partition anchorage drawings, so they were not available. IIT Roorkee was developing a retrofit scheme for the two-storey corridor, which their analysis showed was likely to collapse.

Anticipated Performance After Retrofit

The Ward Block is expected to perform at the immediate occupancy level for the DBE, and at life safety for the MCE, once the brick partitions are braced.

Alternative Schemes Investigated

Delhi PWD performed initial investigations (by linear analysis) of an exterior buttress scheme for the Ward Block, before IIT Roorkee's nonlinear analysis showed that such measures were unnecessary. IIT Roorkee investigated using buttresses to reduce the drift enough to protect the partitions, but found that the buttresses would have to be impractically large.

IIT Roorkee proposed several methods of restraining the brick partitions out-of-plane, including plastered wire mesh and vertical FRP strips, before selecting steel channels. The peer panel recommended the steel channels because they would be quicker, easier and less messy to install than the other options.

Functionality, Architectural, and Disruption Considerations

The hospital is continuously occupied and operational twenty-four hours a day, seven days a week. Any retrofit measures require either vacating the building or working very carefully to manage disruptions during construction. The partition retrofit measures will need to be applied incrementally, in order to minimize the number of beds taken out of service at any one time. When the new base-isolated building opens, the hospital may be able to transfer more patients there, so that construction can continue more rapidly.

Engineering Design and Construction Documents

At the time that this report was written, engineering design was in progress but not yet complete. Engineering drawings, specifications, and cost estimates were not available.

Construction and Quality Control

At the time this report was written, Delhi PWD had not begun to implement the retrofit measures.

Mitigation of Falling Hazards

The hospital has many objects such as mechanical equipment, architectural elements, tanks, pipes, medical equipment, and furnishings that could fall or break during an earthquake. IIT Roorkee prepared an extensive report on these items entitled "Survey of Non-Structural Components at GTB Hospital, Delhi." Because the ward block building and the new base-isolated building will perform well even in the largest expected earthquake, the hospital's equipment, systems and furnishings need to be braced in advance, so that the hospital can function after an earthquake. Delhi PWD plans to anchor these items, after the structural retrofit is complete.

Figure 10. Rigid pipes crossing an expansion joint on the roof (left); unanchored emergency generator (right)

Conclusions

GTB Hospital delivers a tremendous amount of healthcare every day, and its services will be critical following a major earthquake in Delhi. The hospital is still expanding and will have many opportunities to improve its seismic performance. The decision to construct a new base-isolated building, made as a result of what participants learned during this project, is a fine start. The stitching together of the ward block sections, the incremental seismic retrofit of brick partitions inside the ward block, the retrofit of the two-storey corridor, and the anchoring of equipment and building utility systems will permit the hospital to resume operations quickly after a major earthquake. At the time when this report was written, Delhi PWD had not yet begun to implement the recommended seismic retrofit measures. However, Delhi PWD, the Delhi Government, and the other project participants remain committed to constructing this retrofit, so that GTB Hospital can continue to deliver care when it is needed most.