Initial Seismic Vulnerability Assessment of Equipment, Utilities, Architectural Shell and Contents at National Academy of Medical Sciences (Bir Hospital) Kathmandu, Nepal

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Prepared for the World Health Organization Regional Office for South-East Asia by

GEOHAZARDS INTERNATIONAL

A Nonprofit Working Toward Global Earthquake Safety

Acknowledgments

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Executive Summary

The 460-bed National Academy of Medical Sciences (Bir Hospital) is a tertiary referral and teaching hospital offering undergraduate, postgraduate, and specialization training to medical and nursing students and graduate doctors. The hospital is one of the four main hospitals in Kathmandu and offers numerous medical specialties as well as care to Kathmandu's poor. The Advisory Group for the Nepal Risk Reduction Consortium (NRRC) Flagship Project 1, which is tasked with improving hospital earthquake safety in Nepal, identified Bir Hospital as having high priority for assessment due to the critical medical services it provides.

As part of the assessment process, GeoHazards International (GHI) sent a team to Kathmandu in May and June 2013 to assess the potential seismic vulnerabilities of building utility systems, equipment, architectural shell elements and contents (*i.e.*, nonstructural elements) in Bir Hospital and two others, which are assessed separately. The seismic vulnerability assessment of equipment, utilities, architectural shell and contents complements a structural assessment and a functionality/emergency preparedness assessment being conducted by others as part of the larger project. The assessment is intended to provide the hospital, the Ministry of Health and the Regional Office for South-East Asia (SEARO) of WHO with recommendations to improve the hospital's ability to deliver medical care following a major earthquake. The team obtained the information included in this report by conducting in-person evaluations of building contents and utility systems over several days at the hospital; reviewing available technical reports and drawings; holding discussions with the hospital administration and engineering, maintenance and medical staff; and obtaining technical information from the literature. This report presents the GHI evaluation team's findings and recommendations.

The hospital facility has numerous seismic vulnerabilities in its utility systems, equipment, architectural shell and contents, which should be addressed as part of a larger effort to improve the seismic performance and functionality of the facility. Results of the detailed structural assessments were not available at the time of this report, but are of critical importance. Most of the hospital's buildings were built between the late 1960s and mid 1980's, and are unlikely to contain the earthquake-resistant features required by modern building codes. Though structural assessment is outside GHI's scope for this project, it is worth mentioning that the GHI team noted potentially dangerous seismic vulnerabilities in a number of the hospital's buildings, and GHI anticipates that the results of the structural assessments will indicate that some hospital buildings are likely to experience major structural damage in a strong earthquake.

Of the vulnerabilities in GHI's assessment scope, those in the electrical power system present the most serious threat to the hospital's post-earthquake functionality. GHI recommends that the hospital immediately take steps to seismically protect the backup electrical power system and improve its capacity. The other immediate-priority recommendations include restraining medical gas cylinders against toppling, providing backup communications capacity, repairing the non-functional fire suppression system, and ensuring that exit pathways are clear of impediments.

The mitigation and preparedness measures necessary to help keep the hospital functional will take time to implement, and will need to be integrated with the overall seismic safety improvement plan, then planned and spread out over a number of years. Bir Hospital will then be much better prepared to serve the community in the event of an earthquake.

Contents

Introduction

The Nepal Risk Reduction Consortium (NRRC) was established in May 2009 to emphasize the shift in focus of development assistance to a disaster risk reduction perspective. Out of five flagship projects under NRRC, Flagship Project 1 is "School and Hospital Safety-Structural and Non-Structural Aspects of Making Schools and Hospitals Earthquake Resilient." Currently, the World Health Organization (WHO) is coordinating the 'Hospital Safety' component of the Flagship 1 Project with the Ministry of Health and Population (MOHP) as the lead Government of Nepal agency.

The Department for International Development, UK (DFID) is supporting a three-phase project "Improved Seismic Safety of Priority Hospitals in Nepal." An Advisory Group comprised of relevant Government of Nepal agencies, development partners, and other stakeholders was set up for Phases 1 and 2. Phase 1 includes rapid seismic vulnerability screening of 60 hospitals with more than 50 bed capacity. Phase 2 consists of more detailed structural, nonstructural and functional (*i.e.*, preparedness) surveys of 20 hospitals, including six priority hospitals identified by the Advisory Group. The project also has a Phase 3, in which engineers will conduct detailed structural assessments and analyses, design seismic retrofits and estimate retrofit costs for 10 hospitals. Engineers will present retrofit recommendations and initial cost estimates at a donor conference at the end of 2013. WHO engaged GeoHazards International (GHI) to assess the potential seismic vulnerabilities of building utility systems, equipment, architectural shell elements and contents (*i.e.*, nonstructural elements) in several priority hospitals as part of the Phase 2 survey.

The Advisory Group identified the National Academy of Medical Sciences (Bir Hospital), along with Paropakar Maternity and Women's Hospital Thapathali, the Kanti Children's Hospital, and several others, as having high priority for assessment due to the critical medical services they provide on a day-to-day basis. Bir Hospital is one of the four main hospitals in Kathmandu. It provides significant free services, with 331 of the 460 beds being free beds. Bir Hospital is also a teaching hospital at undergraduate and post graduate levels for medical and nursing students. Moreover, the hospital has a number of highly specialized clinical and diagnostic services in almost all the important specializations. The hospital also has a Burn Unit. The Emergency Department has capacity of 22 beds that can be increased to 45 by extending the services to the adjoining entrance area. The hospital occupies an ideal location just across the road from the large open areas of Ratna Park useful for emergency response, as Figure 1 shows.

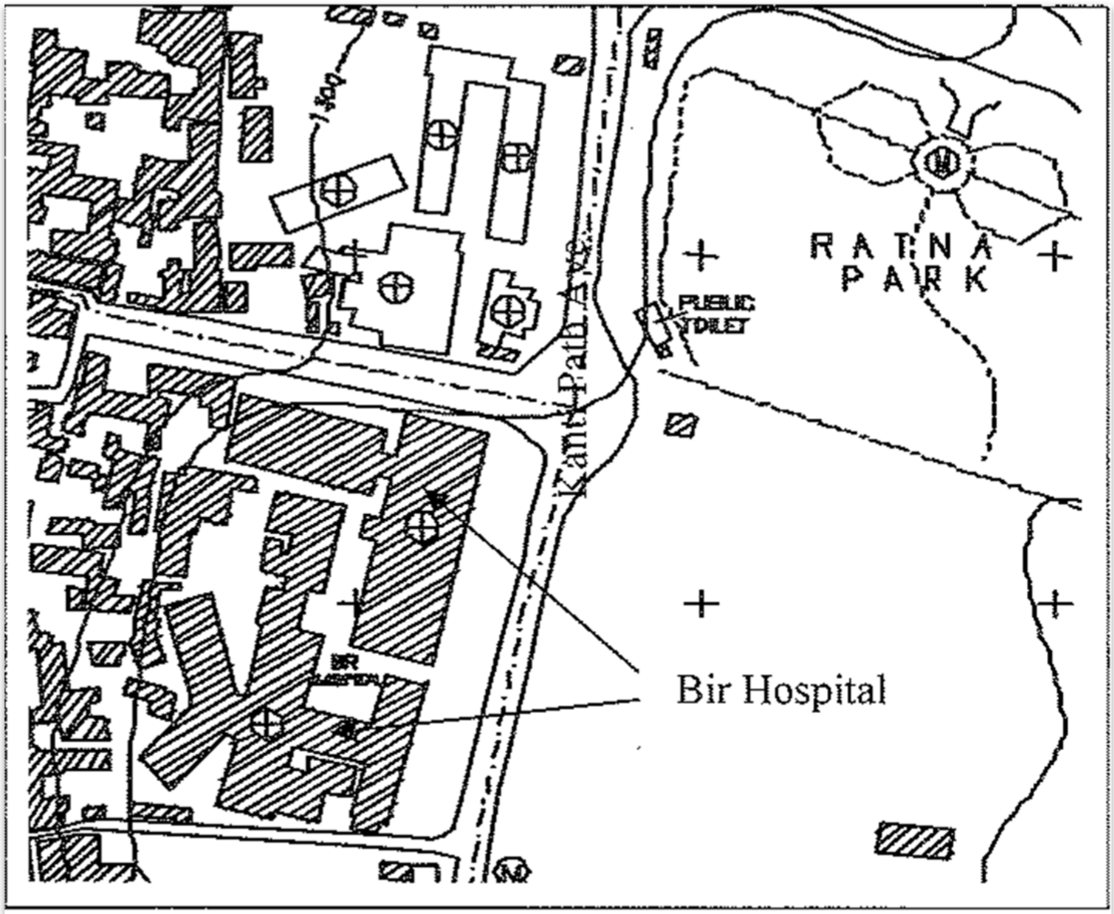

Figure 1: Bir Hospital and surrounding urban context

Assessment Team and Methodology

GHI's field assessment team consisted of Mr. Hari Kumar, GHI South Asia Regional Director, and Dr. Keya Mitra, Professor of Architecture, Bengal Engineering and Science University Shibpur, India. Dr. Janise Rodgers, GHI Project Manager, and Mr. William T Holmes, Senior Consultant, Rutherford & Chekene Structural and Geotechnical Engineers of San Francisco, California helped develop the assessment methodology and recommendations.

Prior to conducting the on-site assessment, the GHI team reviewed available DFID-supported Phase I survey reports, papers, and plan drawings generated during the structural and functional assessments, as provided by WHO. Upon arrival in Nepal, the field team attended a meeting comprised of WHO Representative (WR) to Nepal, DFID, the structural assessment experts, and functional (i.e., preparedness) assessment experts.

In late May and early June 2013, the GHI field team conducted site visits to assess the seismic vulnerability of equipment, building utility systems, architectural shell elements and contents – often collectively referred to as *non-structural components* – in three major hospitals in the Kathmandu Valley, including the Bir Hospital.

During the surveys, GHI used the PAHO (Pan American Health Organization) Hospital Safety Index checklist forms and the UN ISDR/WHO Safe Hospital Indicators document as data collection tools.

The team conducted walk through surveys to assess the potential seismic vulnerabilities of the critical areas of service for normal conditions and emergency management such as the Out-Patient Department (OPD), In-Patient Department (IPD), Operation Theatre (OT), Emergency Ward, and Trauma Centre. The team also assessed the following on-site utility systems: fire suppression; electrical power; drinking water supply; medical gas; communication; heating ventilation and air conditioning (HVAC); lifts; wastewater and solid waste management; major and specialty medical equipment such as X-ray, laboratory, specialty diagnostics; and architectural shell elements such as unreinforced brick partition walls and suspended ceilings.

The team obtained the information included in this report by conducting in-person evaluations of building contents and utility systems over several days at the hospital; reviewing technical reports and drawings where available; interviewing or holding discussions with the hospital administration and engineering, maintenance and medical staff; and obtaining supporting technical information from the relevant literature. The field team held discussions with members of the hospital administration including Medical Superintendents, Maintenance Engineers, Nursing Superintendents and hospital staff in the different departments that were surveyed. The team made efforts to visit all important areas of the hospital without disrupting patient care, but some areas were not accessible due to ongoing medical service delivery.

Scope

The scope of this report includes a seismic assessment of the equipment, architectural shell and contents of the hospital's medical buildings, on-site utility infrastructure, and on-site engineering and maintenance offices. The staff quarters and privately operated dispensaries on the hospital grounds are outside the scope of this report. Some less critical smaller buildings, such as storage sheds, on the hospital campus are likewise excluded from the scope of this report.

Assessments of structural performance of the buildings during earthquake shaking, the potential ground failure and its impacts, and the hospital's level of emergency preparedness are excluded in the scope of this assessment, because they are being conducted by other teams. Knowing the structural performance and potential for ground failure are crucial in order to determine whether the hospital is likely to be able to deliver essential medical care after the shaking stops. The findings in this report must be integrated with the results of assessments of structural performance and potential ground failure in order to draw conclusions regarding whether specific buildings will be usable following a major earthquake.

Earthquake Hazard

Nepal lies in a region of high seismic activity and has a long history of destructive earthquakes. Large earthquakes with magnitude of 5 to 8 on the Richter scale have been experienced throughout the country during the past 200 years, of which 279 earthquakes had epicenters in and around Nepal. In the last century, more than 11,000 people lost their lives in major earthquakes in Nepal. Kathmandu Valley is widely known as one of the most seismically active areas in the central Himalaya, having experienced large earthquakes in the past centuries. The 1934 Nepal Bihar earthquake severely affected the lives and building stock of Kathmandu Valley. This earthquake was not an isolated event. Three earthquakes of similar size occurred in Kathmandu Valley in the 19th century alone, in 1810, 1833, and 1866 AD. Major damage of probable seismic origin is reported to have occurred in 1255, 1408, 1681, 1803, 1810, 1833, 1866, 1934, 1988 and 1991.

The levels of ground shaking expected, and the effects of site conditions, are discussed in the Location and Site Conditions section.

Description of the Hospital

The National Academy of Medical Sciences (Bir Hospital) is a tertiary referral and teaching hospital offering undergraduate, postgraduate, and specialization training to medical and nursing students and graduate doctors. The Hospital was established in 1889 and has grown from a 9 bed facility to its current capacity of 460 beds. In addition to general medical service, Bir Hospital provides services in highly specialized areas including Neurology, Neuro-Surgery, Cardiology, Cardio-Thoracic and Vascular Surgery, Burn and Plastic Surgery, Nephrology, Urology, G.I. Surgery, Gastroenterology, Hepatology and Radiotherapy. The various departments and facilities are housed in the buildings shown on the site plan in Figure 2: (1) Emergency Block, (2) Out-Patient Department Block, (3) Surgical (In-Patient) Block, (4) New Cabin Block, (5) Old ICU Block, and (6) Radiotherapy Block. Single storey blocks for Stores, Housekeeping, Maintenance, and Staff Quarters were outside the scope of the assessment and are not shown in Figure 2.

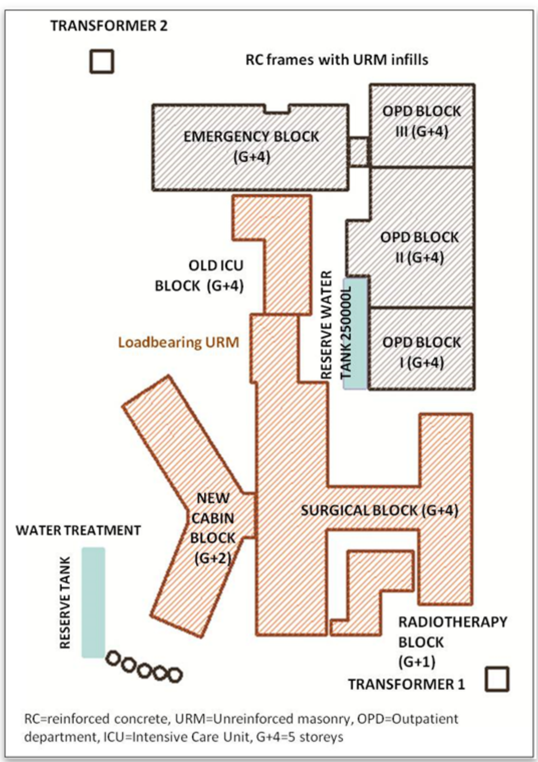

Figure 2: Site Plan adapted from John Sanday and Associates, Pvt. Ltd.

Location and Site Conditions

Kathmandu Valley evolved during the Pliocene and early Pleistocene. It was submerged and after emergence accumulated fertile soil from late Quaternary sediments. The Kathmandu Valley infilling consists of three-million-years-old fluvial and lacustrine sediments delivered mainly from the mountains in northern parts of the basin. The basement is formed by the Precambrian to Devonian rocks, which are mainly meta-sediments, intensely folded, faulted and fractured. They consist of quartzite, phyllite, schist, slates, limestone and marbles. They are overlain by Quaternary sediments in the valley. The sediment cover has a thickness of 550 to 600m in the central part of the valley.

Bir Hospital is located in the Mahabouda area at an elevation of 1298m. The Bishnumati River flows just over a kilometer to the east of the Hospital. According to a WHO-Ministry of Health report from 2002[1], a soil liquefaction analysis carried out next to the existing hospital found a silty sand layer between 6 and 10m below the surface. Liquefaction potential was found to be low, at a depth of 8m; the soil was assumed to be saturated at this depth. The silty sand layer may liquefy during intensity MMI=IX shaking. GHI recommends further investigation of the liquefaction potential, including determination of the hydrostatic water table level. Potential effects of liquefaction on the hospital's buildings should be investigated.

Figure 3: Location of Bir Hospital in Kathmandu Valley

[1] WHO (2002). Mitigating Earthquake Risk in Health Facilities. A Structural Vulnerability Assessment of Hospitals in the Kathmandu Valley.

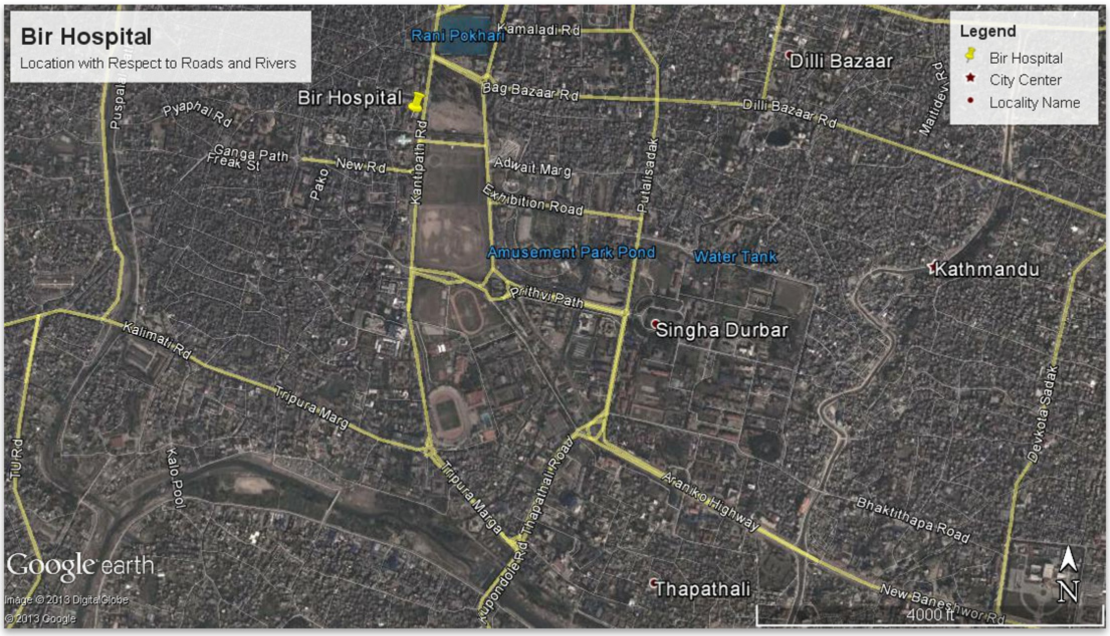

Figure 4: Local transportation routes and proximity to rivers

Assessing the potential for ground failure and site effects is outside the scope of this project, but the level of ground shaking at the Bir Hospital site is likely to be affected by these factors. A JICA (Japan International Cooperation Agency) study in 2000-2001 (JICA, 2000)[2] found amplification factors ranging from 100% to 200% for an intensity MMI-VIII earthquake, considering peak ground acceleration (pga) values to be between 0.2g to 0.35g. Site specific studies should be carried out during the detailed assessment phase to determine the likely values of ground shaking parameters and the potential for ground failure. The WHO-Ministry of Health Report (WHO, 2002) providing the results of a structural vulnerability assessment assumed pga values of 0.2g to 0.35g for MMI-VIII shaking, 0.1g-0.2g for MMI=VII shaking and above 0.35g for MMI=IX shaking. If current site specific studies determine that the anticipated ground shaking will be significantly different than the ground shaking assumed in that report, then the conclusions of this assessment will need to be revisited and potentially adjusted.

Buildings

The main Emergency Block, Out-Patient Department Block and the Surgical Block (In-Patient) are each housed in ground-plus-four-storey buildings built from reinforced concrete frames with brick masonry infill walls and partitions. The ground-plus-two-storey Y-shaped New Cabin Block, ground-plus-four-storey L-shaped Old ICU Block, and two-storey Radiotherapy (Oncology) Block are load bearing unreinforced masonry structures. Table 1 shows key characteristics of hospital buildings included in this report. GHI obtained the year of construction from Phase 1 rapid screening reports.

[2] Japan International Cooperation Agency (JICA), 2002. The Study on Earthquake Disaster Mitigation in the Kathmandu Valley, Kingdom of Nepal. Volume 1. Summary. Nippon Koie Co., Ltd. And Oyo Corporation.

Table 1. Characteristics of Bir Hospital Buildings with Medical Functions

Block	**Year Built**	**No. Storeys**	**Type**	**Major Departments**
Emergency Block	1986 Government of India (GoI)	G+4	Reinforced Concrete w/ brick infill	Emergency Surgical and Medical Observation Emergency Minor OT Emergency Imaging (X-Ray, USG, CT Scan) Emergency Laboratory Emergency Ward Emergency Blood Bank
OPD Block	1986 GoI	G+4	RC w/ brick infill	Surgical OPD Minor OT Ticket Counter Orthopedic OPD Ultrasound and CT Scan Dental OPD Cardiology Christina Dispensary (Private Dispensary) Physiotherapy Library Gynaecology OPD Medical OPD GI OPD Liver OPD Nephrology OPD Hemodialysis Neurology OPD Skin OPD Eye OPD ENT OPD
Radiotherapy (Administration) Block				Administration Neurology OPD Histopathology Lab
Surgical Block (In-Patient)	1968 USAID	G+4	RC w/ brick infill	X-Ray Paying Medical Wards Male Surgical Ward ENT Ward and Cabins Neurology Ward Urology Ward Medical Ward Male Surgical Cabins Orthopedic Ward Central Sterile Supply Department (CSSD) General OT Special OT Neurology ICU NAMS offices Post-operative Ward

New Cabin Block	Late 1970s	G+2	Brick URM	New ICU Radiotherapy (Oncology) Ward Kidney Transplant OT Operation Theatres (OT) Doctor's Duty Rooms Burn Ward Female Medical Ward
Old ICU Block	1976	G+4	Brick URM	Old ICU Male Medical Ward CT based OT, CT, ICU CT Ward

Most of the hospital's buildings were built between the late 1960s and mid 1980's, and none of them is likely to have been built to a code with modern earthquake resistant design provisions. Nepal did not begin efforts to develop a national building code until 1992, and the code was not released until 1994. Modern provisions for earthquake-resistant design of reinforced concrete buildings did not enter Indian codes until 1993, after the Government of India built the Emergency and OPD blocks. Similarly, modern provisions for concrete buildings did not enter codes in the United States until the early 1970's, after the US Agency for International Development built the Surgical Block. In addition, these older buildings are not likely to be well suited to recent advances in medical care and the infrastructure now required to deliver that care.

The GHI team observed that the Old ICU Block, the New Cabin Block and the Radiotherapy Block have structural systems of unreinforced masonry, well known to be vulnerable to earthquake damage. The buildings likely do not have elements such as sill, lintel and roof bands, nor any reinforcements in the masonry walls for the transfer of lateral earthquake loads. The structural walls are likely to suffer significant shear cracking ("X" cracking) and create falling hazards from masonry falling out perpendicular to the wall. In addition, there is no provision in place to simplify the complex plan shapes to create more earthquake resistant configurations. Moreover, the Old ICU Block abuts the Surgical (In-Patient) Block without an adequate seismic gap. The floor to floor heights of the two buildings are different, and so are the structural systems. This makes both of these buildings vulnerable to pounding damage as they impact one another. Such impacts are likely to increase floor accelerations and thus compound the vulnerability of the architectural shell, building utilities, equipment and contents in these two buildings.

The New Cabin Block houses the New ICUs and the Burn Ward. Other important hospital facilities, such as the Oncology Ward and Operation Theatre Suite (with 5 OTs), are located in this building. The Old ICU Block houses the old ICU and CT scan and CT based OT facilities. The seismic behavior of each building, which is being assessed separately, will play a major role in the earthquake effects on the architectural shell, equipment and systems in these departments.

Infrastructure and Utility Services

The hospital's electric power supply comes from the local grid. Feeder lines from two Nepal Electricity Authority (NEA) locations supply electricity to two transformers on the hospital premises. One 165 kVA (132 kW) diesel generator provides backup power, with 100% backup provided to the

Emergency, OTs, Post-operative wards, and the water supply and distribution system. Parts of the Out-Patient Department and wards are provided with nominal power backup. The generator does not switch on automatically and has to be started manually, which is said to take a minimum of ten minutes. Most of the critical departments have battery backup of up to 20 minutes for lighting purposes only, but life support equipment such as ventilators all have inbuilt battery capabilities to run for at least 30 minutes without power. Only two of the four lifts are operational during generator power supply. The Central Sterile Supplies Department (CSSD) is not covered by backup power support. Diesel fuel for the generator is brought in drums by truck and stored in two drums of 200L capacity each and in a 500L tank. The storage drums are located adjacent to the generator. When running, the generator consumes approximately 35L of diesel fuel per hour. The generator and ancillary equipment are kept on a platform and not bolted or braced to prevent lateral movement. The hospital has two recently acquired 250kVA generators that are not currently in use, because the hospital has yet to finalize the location of the generator room on the very constrained site. There is no designated fuel storage area for the new generators.

The hospital does not depend on the municipal water distribution system. One bore well draws water from aquifers 300m below ground level using a submersible 15Hp pump located 215m below ground. The water is treated through an air filter in an aeration tower of 5000L capacity. From the aeration tower, the water is stored in Underground Raw Water Tanks of 250,000L capacity. The raw water is then treated through sand filter, carbon filter, ammonia removal and softening before being stored in five ground-level tanks of 10,000L capacity each. This treated water is pumped to the rooftop overhead tanks located on the roofs of different building blocks. The rooftop overhead tanks have a total capacity of 160,000L. There are three pumps of 5Hp capacity each, out of which two are in operation while one is always held in reserve. The hospital has no central boilers for supply of hot water. There is no central HVAC system in place. Window and split type air conditioners with heating and cooling functions are used. The hospital relies on the city sewer system for wastewater disposal and treatment. Medical waste is incinerated on site.

Medical gas is supplied via oxygen cylinders that are brought in by a supply company truck from Balaju, about 2.5 km away, on a daily basis. The hospital does not have a bulk oxygen tank. Piped oxygen is provided to the OTs and critical areas through a manifold that is fed by 30 cylinders. Individual cylinders provide other medical gases in specific locations as needed.

Observed Earthquake Vulnerabilities

The team assessed the hospital for vulnerabilities in its utility systems, equipment, architectural shell and contents. As noted in the Scope section, an assessment of the seismic structural performance of the buildings was excluded from the scope of this assessment, because others are responsible for structural assessment. Results of the detailed structural assessments were not available at the time of this report, but are of critical importance. The team noted potentially dangerous seismic vulnerabilities in a number of the hospital's buildings, and anticipates that the results of the structural assessments will indicate that some hospital buildings are likely to experience major structural damage in a strong earthquake.

Vulnerability of Utility Systems and Backup Capabilities

Hospitals rely on utility systems such as electrical power, water and medical gases to function. Under normal operating conditions, utilities such as electricity are supplied by the local grid. Earthquakes often cause outages of off-site utility systems, and most hospitals have backup capabilities that can also be vulnerable to earthquake damage. Supply and distribution systems for other utilities such as medical gas can be vulnerable to earthquake damage that can interrupt utility services and interfere with or prevent essential medical service delivery following an earthquake. The following sections present utility system vulnerabilities that the evaluation team observed.

Electrical Power System

The hospital's most important utility system is the electrical power system. Without power, the hospital's essential medical equipment, life support equipment and other safety-critical items will not function. Off-site power comes from the municipal power supply through two independent 11kVA feeder lines. According to a study conducted in 2002 by NSET, the municipal power supply would become unstable during an earthquake generating Intensity VII shaking. This would cause power disruption. Estimates of the time it would take to restore grid power following earthquakes of different magnitudes were outside the scope of this investigation, but GHI recommends that the hospital obtain these estimates from Nepal Electricity Authority for planning purposes.

The hospital has two transformers of 250kVA capacity each. The transformers that receive the grid power supply are placed on a concrete platform resting on the floor. The bolting details of the platform could not be determined by visual inspection. There is no evidence of the structure being anchored to the concrete platform with steel plates and anchor bolts; thus the platform is prone to sliding or toppling (Figure 5). Even if grid power returns, the hospital may not be able to access it due to damage to the transformers or their connections to the power lines. During the critical response period immediately following an earthquake, the hospital will need to rely on backup power.

Figure 5: Transformer not secured to the concrete base

The evaluation team observed multiple vulnerabilities in the backup electrical power system, which are likely to cause backup system to fail in a strong earthquake and possibly in a moderate earthquake, leaving the hospital completely without power. A single 165kVA emergency generator supplies backup power to several critical areas in the hospital. Two 250kVA generators are present but not operational. In comparison, due to the critical need for electrical power, a number of tertiary care hospitals in the region have two (or more) generators to provide redundancy in case of mechanical failure, and to allow for rotating operation of the generators during a lengthy grid power outage.

The generator must be started manually, and it will take at least 10-15 minutes for the generator to be started following power failure, because it is located in a separate, unstaffed structure that the staff member concerned will have to reach in the immediate aftermath of the earthquake. The generator is housed in what appears to be an old, load bearing unreinforced masonry building. The wall thickness indicates that the walls may be double wythe brick masonry. Structural assessment of the generator building was beyond the scope of this report, but unreinforced masonry buildings often perform very poorly during strong earthquakes. Because it contains such critical equipment, potential structural vulnerabilities of the generator building should be assessed. Maintenance staff at the hospital reported that power cuts are not a common occurrence in the hospital, and that the maximum time that the hospital had to run on generator support was 12-13 hours. The generator is tested every two days in the early morning for about 10 minutes. The generators are cooled with coolant, which must be added manually. Overheating after long periods of use might be a problem.

The emergency generator is not anchored and will slide off of the vibration isolators during strong earthquake shaking, as Figure 6 shows. The generator's exhaust system is not braced and may be damaged, which can render the generator inoperable. The batteries that enable the generator to start up are not anchored and may break or become disconnected.

Figure 6: Generator without proper anchoring to the base plate

The generator has a tank that holds 500L, and additional fuel is stored in two drums of 200L capacity each. The fuel is procured from a petrol pump located about 4km away. If the tanks and drums are full, the hospital will have enough fuel for 25 hours of operation under normal conditions. PAHO recommends that hospitals store enough fuel to power the backup generators for at least five days. The tank lacks flexible piping, and the supply of generator fuel would be affected if the rigid pipes break during earthquake shaking (Figure 7). The generator is located in a secure place on the ground floor, safe from the elements, but not protected against earthquake shaking. The hospital has no history of being affected by flooding from the nearby rivers. The fuel drums are located in a secure location but are not anchored to prevent toppling and spillage during an earthquake (Figure 8, left). Cables are placed haphazardly and not laid on cable ducts (Figure 8, right).

Figure 7: Generator fuel tank without flexible piping

Figure 8: Reserve fuel drum without anchoring, susceptible to toppling and spillage and posing a fire hazard (left); No ducting or trays for electrical cables (right)

The generator provides 100% support to the Emergency Block, all OTs, Post-operative wards and to the water distribution system, with nominal support to parts of the Out-Patient Department and other wards. The CSSD is not supported by the generator. In the event of a long power disruption, this would affect the functionality of the OTs, which would have power from the backup system but no sterile supplies.

The main electrical equipment is also not anchored to the wall to prevent toppling during earthquake shaking. The central electrical control panel is located in an inaccessible part of the site and has to be approached through one of the patient wards. Moreover, the access path is used for drying laundry and littered with leftover food and other discarded items. The electrical cabinets housing switchgear and controls may be unanchored (the team was unable to verify anchorage) and could topple because they are tall and narrow.

Of the vulnerabilities in GHI's assessment scope, those in the electrical power system present the most serious threat to the hospital's post-earthquake functionality.

Water Supply System

The hospital does not use the water from the municipal supply. Water is drawn from the aquifer level through a single bore well using a 15hp submersible pump. The water supply system is fully supported by the power backup system and will therefore function during any interruption in the power supply. However, the earthquake could damage the treatment system and the backup power system, halting the ongoing supply of treated water. Adequate water storage facilities are a critical component in ensuring continued functionality of a hospital after a seismic event. PAHO recommends that hospitals have domestic water storage capacity of at least 300L per day per bed for at least three days. For 460 beds, the hospital should have 138,000L per day (and 414,000L for three days) storage capacity for domestic water. At present the hospital has storage capacity for 160,000L of treated water, which is about one day's supply. Moreover, leaks in the piping system due to earthquake damage could cause the tanks to empty from gravity pressure.

Water storage tanks for untreated water are located in secure locations, but there are no measures to protect them against damage from shaking. Evaluation of the seismic resistance of the ground-level reinforced concrete water tank was outside the scope of this assessment, but it is possible that the tank, the unreinforced masonry pump house, or the pipes connecting the tank to the hospital could be damaged and cause leakages. The inlet and outlet pipes do not have flexible connections, and the rigid connections could be damaged in earthquake shaking.

The water treatment equipment is located in an open, easily accessible area near the southwest corner of the wedge-shaped New Cabin Block building (see site plan in Figure 2). The water storage tanks for treated water are located quite close to the boundary wall of the hospital. This unreinforced brick masonry wall does not have any bracing elements to help resist out-of-plane toppling (Figure 9). If this boundary wall collapses, it could in turn damage or topple the water storage tanks and impair water supply to the hospital. Untreated water is stored in a ground level reinforced concrete water tank with 250,000L capacity (Figure 10). The tank appeared to be in reasonably good condition.

Figure 9: Unreinforced brick masonry boundary wall may topple due to out-of-plane forces and cause damage to the water storage tanks

The untreated water is subjected to four levels of treatment, namely, sand filter, carbon filter, ammonia removal and softening. The four treatment tanks are GI (Galvanized Iron) tanks with rigid inlet and outlet pipes, and with no flexible connectors that would protect against breakage during earthquake shaking (Figure 11).

Figure 10: Ground level reinforced concrete water storage tank shown by yellow dashed line

Figure 11: Rigid piping in sand filter tank (left);
Rigid pipes in carbon filter, ammonia removal and softening tanks (right)

Fire Suppression System

There is no separate water tank for fire fighting, nor does the hospital have an operational fire fighting system in place. The fire suppression system installed at the time of construction of the OPD and Emergency Block has been out of commission for more than two decades. There is no external fire hydrant on the hospital premises. Municipal Fire Services is located about half a kilometre from the Hospital, and there is a reserve tank on their premises. The field team observed a number of fire extinguishers which will presumably be used by the security personnel in case of a fire. None of the staff members the team interviewed had received training to use fire extinguishers. The lack of a proper fire suppression and fire fighting system is a major deficiency.

Medical Gases

There is no centralized piped gas system serving the entire hospital. The oxygen bank supplies piped oxygen only to the Operation Theatres and Post-Operative Wards. Other gases, such as nitrous oxide for the Operation Theatres and oxygen for other locations, are supplied by individual cylinders. The central suction system and its piping are not operational.

The oxygen bank does not have a large tank, but instead uses a manifold with 30 unanchored cylinders that are connected to it by semi-flexible copper tubing (Figure 12). During an earthquake, many of these cylinders will topple, disconnect from the manifolds, and possibly leak, leading to a possible fire and explosion hazard. The Hospital has a daily requirement of 60-80 oxygen cylinders, but has storage space for only 30 cylinders (in addition to the 30 cylinders in the manifold), which means there is only half a day's supply of oxygen or less. While the piping is secure, there is no flexibility where the lines cross expansion joints and extend into a different building (Figure 13). This lack of flexibility may cause damage during lateral shaking. The medical gas storage facility is accessible, and the cylinders and related equipment are fairly well protected from hazards other than earthquake damage; trained personnel operate the dedicated gas storage area. However, the earthquake hazard is significant because the medical gas storage building is an unreinforced masonry building, which may be damaged during earthquake shaking and disrupt the oxygen supply system. Oxygen and other medical gas cylinders are not restrained in any of the storage locations in the hospital (Figure 12, Figure 14).

Figure 12: Unanchored gas cylinders connected to manifold through flexible piping

The Hospital's gas supply outlet is located about 2.5km away. Assessment of the medical gas supplier's facility was outside the scope of this assessment. However, the hospital's emergency plan should account for the possibility that the supplier's facilities may be damaged, that the supplier's electrical supply may be damaged, and that roads between the hospital and the supplier may be blocked with debris from collapsed buildings. The average daily gas supply is about 80-100 cylinders against a daily requirement of 60-80 cylinders for a 24 hour cycle. Only about 30 cylinders are kept on reserve at the oxygen bank, which constitutes a half day reserve capacity, while PAHO recommends a 15-day reserve. The Hospital should consider increasing the reserve capacity of cylinders to an amount based on a realistic assessment of the supplier's ability to continue providing medical gas, and of the time for roads to the supply outlet to be cleared.

Figure 13: Lack of flexible connections at gas pipe bends

Figure 14: Unrestrained oxygen cylinder storage

Communication Systems

The hospital currently uses landline and mobile phones as the major communication systems. Internet and telephone cables are not properly laid out, which may impede repairs if there is damage to these lines. Damage will likely occur to the lines at locations where differential movement is expected, such as seismic joints. However, neither landline nor mobile phone systems are likely to be functional in the aftermath of a significant earthquake affecting Kathmandu Valley. As numerous past earthquakes have shown, phone systems often become overloaded with calls and go down even if damage is limited. In more damaging earthquakes, phone system equipment, such as mobile phone transmission towers and landline central switching stations, can be damaged. While the length of the outage depends on vulnerabilities in Kathmandu's landline and mobile phone systems (which are outside the scope of this assessment), the Hospital should assume neither will be available for several days or more following a major earthquake.

There is no radio or satellite communication system available, leaving the hospital with no backup communications system. A public address system exists that uses loudspeakers, which were found to be in satisfactory condition, though not properly anchored to the walls lacking battery backup.

Heating, Ventilation and Air Conditioning Systems

While the hospital does not have a central HVAC system or boilers, the buildings do have numerous small air conditioning units. A number of these units are sitting unanchored on narrow exterior façade ledges; they can fall during strong shaking and would injure or kill anyone below.

Lifts and Vertical Transportation

The hospital has four lifts, located in various blocks, but only two lifts are operational during generator power supply. The evaluation team assumed that the lifts were not designed for earthquake forces, because there are no seismic provisions for lifts in the Indian Standard codes, and the buildings were constructed prior to development of the Nepal National Building Code. The lift rails and counterweights are therefore assumed to be vulnerable to earthquake damage. During strong shaking, the counterweights can derail and crash through the top of the lift car. The field team did not obtain access to the lift machinery and controls, which were presumed to be unanchored. It should be noted that lift machinery is located at the top of buildings. Shaking tends to be strongest at the top of buildings because the building amplifies earthquake motions. Movement of patients from damaged areas of the facility, or complete evacuation, is difficult and time consuming using only stairs.

The reinforced concrete stairs are attached at both ends and hence will tend to act as braces between floors, causing them to experience large earthquake forces and become damaged during strong shaking. The frames beside the staircase have infill walls that may fall out-of-plane and may fall into stairwells and block the staircase partially or fully.

Vulnerability of Medical Equipment and Contents

The field team conducted a visual survey of the medical equipment and contents in some critical areas of the hospital that will play an important role in providing diagnostic and treatment facilities after an earthquake, listed in Table 2.

Table 2: Areas Assessed for Seismic Vulnerabilities of Medical Equipment and Contents

	Block	Department
1.	Emergency Block	Emergency Surgical and Medical Observation Emergency Minor OT Emergency Imaging (X-Ray, USG, CT Scan) Emergency Laboratory
2.	OPD Block	Surgical OPD Minor OT Administration
3	Surgical Block	X-Ray Orthopedic Ward Central Sterile Supplies Department (CSSD) General OT Post-operative ward Neurology ICU
4.	New Cabin Block	New ICU Oncology Ward Burn Ward
5.	Old ICU Block	Old ICU Male Medical Ward CT, ICU

Many of the medical equipment and storage systems have not been secured or anchored for protection against earthquake shaking. In the Operation Theatres and Post-Operative Wards, lamps, anesthesia equipment and surgical tables are in fair condition and operational. However, not all of the equipment is properly secured (Figure 15).

Figure 15: Operation Theatre with OT lights, equipment and surgical table

X-ray and imaging equipment is in good condition and is secured (Figure 16). The condition and safety of medical equipment in the Emergency Services Department is fair, but the equipment is not adequately secured. This is also true for table top equipment in the Pathology Department, both in the Emergency and in the OPD Blocks (Figure 17).There is a water leakage problem in the Emergency Laboratory, with waste water disposal pipes dripping water on the work surfaces in the laboratory (Figure 18).

Figure 16: X-Ray machine bolted to the floor.

Figure 17: Table top medical equipment without anchoring or restraining

Figure 18: Seepage in the Emergency Laboratory

In the Intensive Care Units and Post-Operative Wards in the New Cabin, Surgical (In-patient), and Old ICU Blocks, the equipment was found to be in satisfactory and even fair condition, but without adequate securing and anchoring. The pharmacy has floor-to-ceiling shelving, overflowing with medical supplies. The shelves have no devices for restraining the contents against falling, breakage and spilling during earthquake shaking. Moreover, the tall floor-to-ceiling shelving is not anchored (Figure 19). It is likely to be difficult to even enter or exit this room after strong earthquake shaking.

Figure 19: Unanchored shelves with unrestrained contents in the pharmacy

The Burn Unit has nine beds and the equipment is in fair condition but not adequately secured. Many oxygen cylinders that are not restrained by any means (Figure 20) are stored at the entry to the Burn Unit. These would topple in an earthquake and block the exit from the Burn Ward. A major concern regarding the Burn Unit is its location in the New Cabin Block, an unreinforced masonry building, a type of building that has behaved poorly in previous earthquakes.

Figure 20: Unrestrained oxygen cylinders at the entrance to the Burn Ward

The Central Sterile Supply Department (CSSD) located in the ground floor of the Surgical Block has two autoclaves at risk of functional failure due to earthquake damage, which would leave the hospital without a way to sterilize surgical instruments. The autoclaves are not bolted to the floor or fastened to the walls (Figure 21), and might overturn and suffer damage during strong shaking. The rigid piping will likely be damaged in significant shaking and affect the functionality of the CSSD (Figure 22). Even if anchored, the autoclaves would stop functioning in case of grid power failure, because they are not connected to the hospital's backup power supply system. Though the OTs have full power backup, operations could not be performed without sterile supplies.

Figure 21: Autoclave in CSSD not bolted to floor or anchored to wall

Figure 22: Rigid piping in autoclaves

In all the treatment and diagnostic facilities surveyed, the work tables, computer tables, laboratory shelving, and storage units are not adequately secured or fastened for protection against lateral shaking (Figure 23). Moreover, in numerous locations, tall shelves full of glass contents are placed next to exit doors. They will likely topple in an earthquake, spilling their contents and broken glass on important evacuation routes (Figure 24).

Figure 23: Unrestrained furniture and equipment susceptible to toppling and sliding

Figure 24: Unsecured shelves with pathological contents susceptible to breaking, spillage and blocking of exit routes

Vulnerability of Architectural Shell and Egress

The hospital's reinforced concrete buildings have numerous single wythe (110mm thick) unreinforced brick partitions. Due to their very high height-to-thickness ratio and lack of tensile capacity, these partitions are vulnerable to severe cracking and collapse during strong shaking. Large cracks in partitions tend to cause concerns about the building's safety among occupants, and are problematic for infection control. Partition collapses can injure or kill people and can result in a loss of defined functional spaces. Incapacitated patients would be especially vulnerable to collapsing partitions, due to their inability to take protective actions during shaking.

The 230mm thick floor-to-ceiling brick infill walls separating the different functional spaces in the Emergency Laboratory and Blood Bank have floor-to-ceiling cracks, both transverse and diagonal, indicating possible mild distress in these walls (Figure 25). This needs to be thoroughly investigated through non-destructive testing to ascertain the strength and condition of the materials and the adequacy of the infill walls. Weakness here could significantly affect the Emergency Department's ability to deliver care post-earthquake, because collapse of these infill walls during shaking would render the Blood Bank and Emergency Laboratory in-operational.

Figure 25: Infill walls with long continuous cracks in the Emergency Lab and Blood Bank

In addition to brick partitions, the hospital has a number of metal and glass partitions in the Emergency Block and OPD Block. The glass in these partitions can break, creating an impediment to egress and potentially injuring those nearby or those who need to walk across the broken glass in inadequately protective footwear.

The hospital has few suspended ceilings, and these ceilings (in several OTs and corridors) are either plaster or metal. Fortunately, the team did not observe any lay-in acoustical tile ceilings, which are more vulnerable to earthquake damage and cause significant disruption when they fail. Door widths are uniformly 4 feet with two leaves of unequal width. In most rooms, the narrower 1-foot leaf is used while the 3-foot leaf is kept permanently shut (Figure 26) and at times blocked with furniture (Figure 27), which could seriously impede egress in an emergency.

Figure 26: Narrower leaf of door kept open while wider leaf is kept shut

Figure 27: Wider leaf of door blocked by furniture

The condition of windows and shutters is poor, and window glass may shatter and hinder evacuation and egress. The thin stone cladding elements (using a kind of terrazzo in which irregular stone panels are set in the facing panels) of the external walls may fall off in moderate to severe shaking and cause injuries on the ground. This would be critical at the hospital's main access areas. The facades of some of the buildings have architectural projections, both horizontal ledges and vertical pilasters, which are not part of the structural system (Figure 28). It is not known how these are anchored to the structural system; if the connections are weak, these elements may constitute falling hazards. Falling debris would make the open air spaces between the buildings quite unsafe for pedestrians and for any post-disaster activities such as assembly or triage.

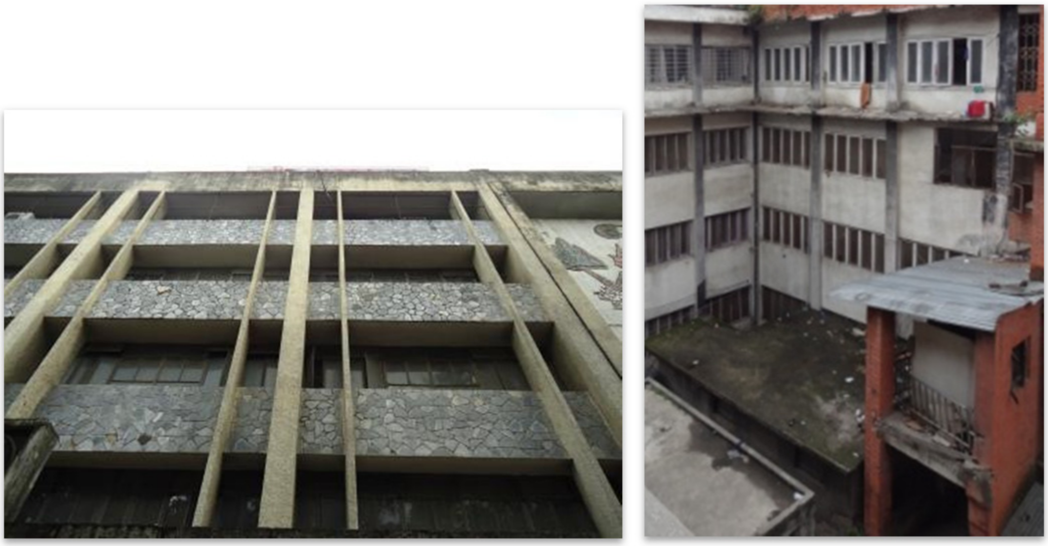

Figure 28: External cladding above the entrance (left) and horizontal and vertical projections of the building facades (right)

Recommendations and Conclusions

The hospital facility has numerous seismic vulnerabilities in its utility systems, equipment, architectural shell and contents, which should be addressed as part of a larger effort to improve the seismic performance and functionality of the facility. Most of the hospital's buildings were built decades ago, between the late 1960s and mid 1980's, and are unlikely to contain the earthquake-resistant features required by modern building codes. Critical medical departments are housed in two multi-storey unreinforced masonry buildings, a type that past earthquakes have shown to be highly vulnerable to major structural damage or collapse during strong shaking. If such damage were to occur at Bir Hospital, it would severely endanger the hospital staff and patients. For this reason, conducting a detailed assessment of the earthquake vulnerabilities of the hospital's buildings, as is occurring during the second and later phases of the current project, must take the highest priority. In addition, these older buildings may not be functionally suited to delivering modern medical care. A number of the hospital's buildings are likely to need seismic retrofit or replacement. As an interim measure to reduce risk, the Hospital can consider relocating critical services to less vulnerable buildings.

Experiences in major, ongoing hospital seismic safety improvement programs in Turkey and California demonstrate that there are a number of serious and significant issues involved when seismically retrofitting hospitals. These include disruption to existing operations if hospital buildings cannot be vacated; increased construction time and costs to manage the disruption; cost to construct the extensive structural retrofit measures often needed in older buildings to provide the high level of seismic performance desired for hospitals; cost to anchor and brace utilities and the architectural shell to prevent damage that would cause shutdown of critical services areas; cost to repair building elements in poor or deteriorated condition; and the fact that for all the effort, medical staff are still using a building that may not suit their care delivery needs. As a result, a number of hospital buildings in Turkey and California have been replaced with new buildings designed for high seismic performance and modern medical care delivery, rather than being retrofitted. Replacement may well be a preferable option for some Nepal hospital buildings as well.

The recommendations in this section must be integrated into decisions to replace or seismically retrofit seismically vulnerable buildings. While GHI recommends that the highest priority recommendations be implemented as soon as possible, without waiting for retrofit or replacement to take place, the remaining recommendations will be most cost effective if performed in conjunction with a seismic retrofit or other construction. If the building is replaced quickly, the remaining recommendations for that building would not need implementing.

The following sections list specific recommendations to address seismic vulnerabilities identified in prior sections, organized by the major utility system and/or element type. Table 3 organizes the recommendations by level of priority.

Backup Electrical Power

The two new generators should be connected with the backup power supply system as soon as possible. The generators must have automatic switchover to backup facilities, including battery racks for uninterruptible power. All three generators need to be seismically protected so that they will not come off their supports, and so that exhaust systems remain undamaged during shaking. Until the new generators and automatic switchover system come online, the hospital should continue the practice of providing all critical medical equipment with emergency backup power independent of the hospital's manually started backup generator. The onsite electrical power backup system is highly susceptible to failure even in moderate earthquake shaking, and it needs significant strengthening to support the hospital's emergency power needs until power supply from the main grid is restored. The hospital should also store the PAHO recommended five days of fuel, or enough to last through the expected length of the grid power outage, whichever is longer. The generator building appears to be unreinforced brick masonry and should receive a structural evaluation.

Communications

The hospital should obtain backup communications capability internally and externally, to enable coordination with other hospitals, government agencies and responders after a major earthquake.

Water Systems

Overhead (rooftop) tanks need anchoring to prevent sliding or toppling in moderate to severe earthquake shaking. Anchor water treatment equipment to prevent damage that would disable the treatment system. Replace rigid connections to the water tanks and to filtering/ water treatment equipment with flexible connections, to accommodate differential movement and prevent breaks that could drain the tanks. Water supply lines crossing building joints should have flexible connections at the joints sufficient to accommodate the expected amount of differential displacement.

Medical Gas

Cylinders in the oxygen bank, outside the Burn Ward and in other locations, need restraints to prevent them from toppling during earthquake shaking. At present the hospital does not have adequate backup supply of oxygen cylinders to last more than half a day of normal use. There should be provisions for storage of at least five days' supply within the premises. (Even though PAHO recommends a 15-day supply of medical oxygen, the lack of storage facilities at Bir may make it difficult to store the recommended 15-day supply on site.) Medical gas lines crossing building joints should have flexible connections.

Lifts and Vertical Transportation

The earthquake safety and functionality of the lifts (especially the two lifts that are connected to backup power supply) should be ascertained by a qualified structural engineer, and corrective actions should be taken if found necessary.

Medical Equipment, Contents and Furnishings

The Hospital needs to make an inventory of the most critical medical equipment and determine whether or not it is adequately anchored or protected against seismic forces. For any new equipment, seismic anchorage should be included as part of the purchase contract. The pharmacy should have anchored racks and shelf restraints.

Architectural Shell and Egress

The numerous brick partitions that are located in areas where critical care is delivered, or where patients and staff could be struck by falling masonry, should be braced with vertical steel members called strongbacks to prevent partition collapse. Exterior cladding elements located above hospital entrances and locations where people congregate need to be evaluated to verify that they can remain in place during the expected earthquake shaking.

Recommended Priorities for Implementing Mitigation Measures

The table below shows recommended priorities to help guide implementation efforts.

Table 3. Recommended Priority Levels for Specific Mitigation Measures

Priority Level	Specific Mitigation Measures
Highest (Critical safety)	• Seismically protect emergency generator • Anchor generator base • Brace muffler / exhaust system for backup power • Restrain batteries • Restrain fuel tanks • Restrain medical gas cylinders against toppling • Provide backup communications capacity • Repair the fire suppression system • Relocate furnishings and contents blocking portions of doorways necessary for emergency egress • Assess adequacy of stairs and ramps to withstand earthquake shaking
High (Critical care delivery)	• Seismically protect and bring online the two non-operational generators • Store additional fuel for emergency generators • Assess generator building structure capacity to resist earthquake demands • Extend backup power to the CSSD • Seismically protect water system components • Install flexible connectors and shutoff valves on water tanks, to prevent a pipe break from draining the system • Anchor tanks, especially rooftop tanks • Ensure that tanks for water treatment chemicals are anchored and have flexible connectors, to prevent leaks • Anchor critical equipment such as pumps • Assess the potential for shaking or liquefaction damage to the boreholes, submersible pump and pipe connections • Secure major medical equipment in critical care areas • Install shelf restraints in pharmacy, key storage serving critical care areas, and medical records to reduce cleanup required post-earthquake • Anchor sterilizers / autoclaves • Brace racks and install shelf restraints in the CSSD, to keep important sterile supplies on the shelves • Restrain brick partitions with strongbacks in critical care areas, or replace with lightweight partitions • Brace or remove exterior falling hazards above exit doors

Priority Level	Specific Mitigation Measures
	• Ensure maintenance/ refilling of fire extinguishers; train staff members in the use of emergency fire fighting equipment
Medium	• Increase water storage capacity • Secure high-value or difficult-to-replace medical equipment in laboratories and other areas • Restrain brick partitions near patient beds in wards, or replace with lightweight partitions • Relocate or anchor large and heavy furnishings in work or patient areas • Install flexible connectors on water and medical gas pipes
Lower	• Restrain remaining brick partitions • Secure remaining medical equipment

Conclusions

The mitigation and preparedness measures necessary to help keep the hospital functional will take time to implement, and will need to be integrated with the overall seismic safety improvement plan to retrofit or replace buildings, and then planned and spread out over a number of years. The hospital will then be much better prepared to serve the community in the event of an earthquake. Because Bir Hospital is one of the largest and most important hospitals in the Kathmandu Valley, these measures are of critical importance to help keep the hospital functioning after a damaging earthquake.