Initial Seismic Vulnerability Assessment of Jigme Dorji Wangchuck National Referral Hospital Thimphu, Bhutan

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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

Executive Summary

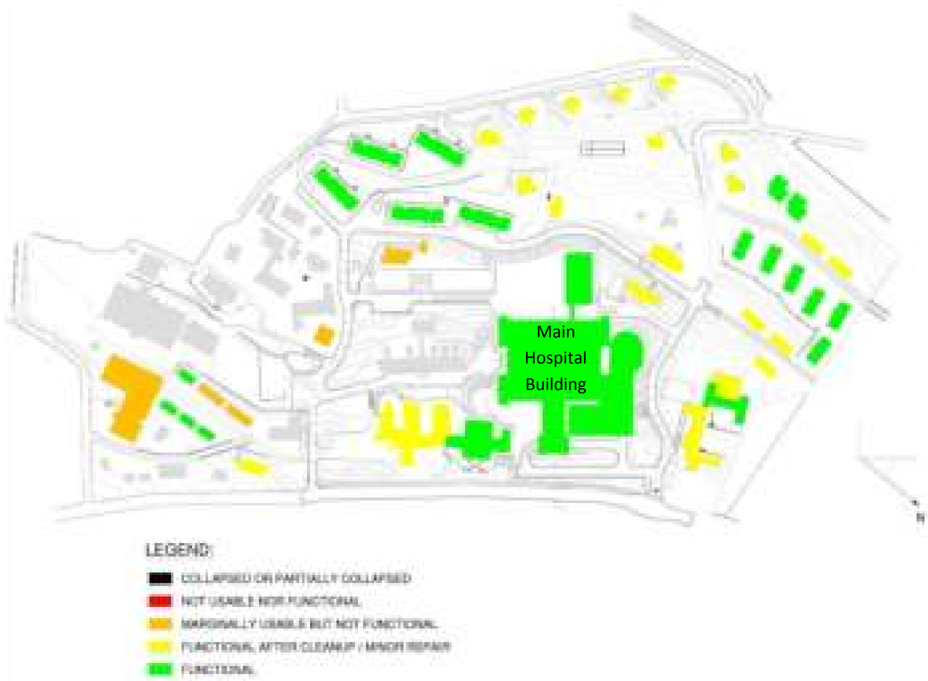
Jigme Dorji Wangchuk National Referral Hospital (JDWNRH) is Bhutan's most important hospital, as well as the only major hospital providing medical care in Thimphu, the capital city. Few hospitals in the world face the type of earthquake threat that JDWNRH faces: high earthquake hazard combined with a geographic isolation that will make post-earthquake relief and resupply difficult, with no other similarly equipped hospitals nearby to help meet healthcare needs. World Health Organization's Regional Office for Southeast Asia (SEARO), the Royal Government of Bhutan, Ministry of Health (MoH), Department of Disaster Management (DDM) and GeoHazards International (GHI) agreed that the hospital will have an essential role following a damaging earthquake and that an assessment of the hospital's current level of earthquake safety and preparedness was necessary.

In May, June and July 2012, GHI performed an initial seismic vulnerability assessment of JDWNRH. The assessment is intended to provide the hospital, the Ministry of Health and SEARO with an overview of the hospital's seismic vulnerabilities, and to recommend actions to improve the hospital's ability to deliver medical care following a major earthquake affecting Thimphu. This report presents the GHI evaluation team's findings and recommendations.

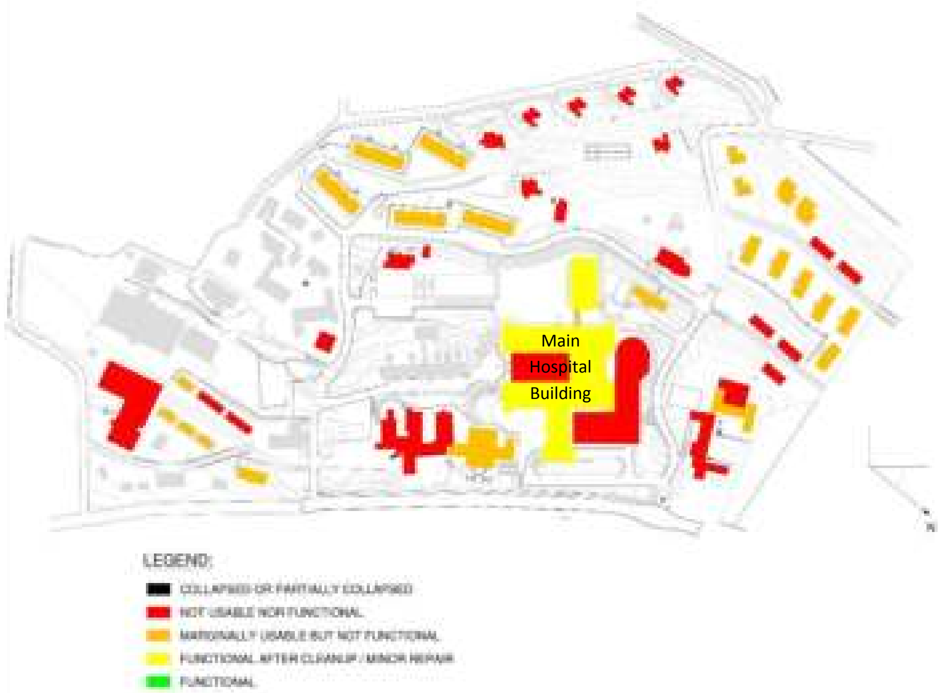
Evaluation team members obtained the information included in this report through conducting in-person evaluations of buildings and infrastructure over several days at the hospital site; reviewing available structural, architectural and utility service design drawings; interviewing or holding discussions with the hospital's administration and engineering, maintenance and medical staff; and obtaining supporting technical information from the United States Geological Survey (USGS), Royal Government of Bhutan Department of Geology and Mines (DGM) and relevant literature. The hospital's ability to function also depends on several interdependent off-site transportation and utility systems, which are beyond the scope of this report but which should be evaluated as part of a larger effort to prepare Bhutan's health system for the next major earthquake.

The evaluation team found that the hospital had a number of seismic vulnerabilities in its buildings, on-site utility infrastructure, medical equipment and emergency preparedness. However, this report goes beyond simply classifying the damage potential of buildings and systems, in order to address consequences. It also introduces three scenarios, or postulated earthquake events. Each scenario is based on a hypothetical earthquake and is intended to illustrate the range of earthquake shaking that the hospital should consider for mitigation and emergency planning purposes. The three hypothetical earthquakes are: (1) a moderate M6.1 earthquake occurring near Thimphu; (2) a major M7 earthquake occurring near Thimphu; and (3) a massive M8.6 earthquake affecting much of the country.

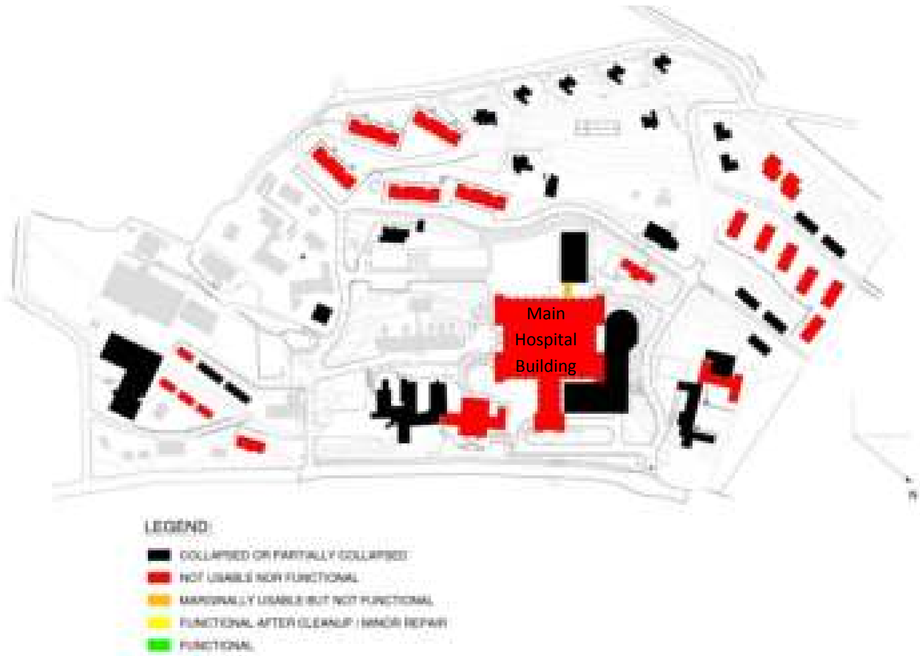
The figures below show the anticipated performance of the hospital's buildings, in terms of functionality, for each of the hypothetical earthquakes. This report defines *functionality* as the combination of building usability – determined by damage to the building, important equipment and contents – and availability of critical utility services supplied by on-site backup systems. The actual state of functionality after a real earthquake is highly uncertain, due to uncertainty in the nature of ground shaking and in the team's existing knowledge of each building's structure, utility systems, architectural elements and contents. Each building could be one performance level higher or lower than shown here; a single performance level is shown for illustrative purposes.



Site plan showing likely performance of hospital buildings in M6.1 hypothetical scenario earthquake



Site plan showing likely performance of hospital buildings in M7 hypothetical scenario earthquake



Site plan showing likely performance of hospital buildings in M8.6 hypothetical scenario earthquake

The JDWNRH is vulnerable to earthquakes in many ways, but it also has intrinsic strengths (including a recently built main building) that should make it possible, by implementing a number of reasonable mitigation measures, for the hospital to remain at least minimally functional following all but the largest anticipated earthquakes. With more extensive investment in seismic upgrades, the hospital should be able to continue delivering essential medical services following even very large earthquakes.

The evaluation team's highest priority recommendations for improving the hospital's ability to deliver medical care after an earthquake are to:

- Strengthen the hospital's backup utility systems, especially the electrical power system, and to protect the hospital's critical medical equipment. Simple, cost-effective measures taken now will substantially increase the hospital's ability to remain functional after a strong earthquake.
- Write an emergency plan that provides guidance for hospital operations following a damaging earthquake affecting Thimphu, and to test the plan with a scenario-based exercise involving ministries responsible for health, transportation and utilities;
- Develop a long-term facilities improvement plan to replace or retrofit those buildings that do not meet seismic performance goals, especially those that are vulnerable to collapse or life-threatening damage; and
- Train the staff to respond effectively following an earthquake.

GHI recommends that the hospital begin working immediately to improve the facility's performance. The mitigation and preparedness measures necessary to help keep the hospital functional will take time to implement and will need to be planned and phased over a number of years. However, the hospital can make major improvements in the next several years. The hospital will then be far better prepared to serve the people of Thimphu, when the next earthquake strikes.

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Introduction

Jigme Dorji Wangchuck National Referral Hospital (JDWNRH) is Bhutan's largest, best-equipped and most important hospital. It is the only facility in the country that offers certain important medical specialties and equipment. Bhutan's government health system (currently the only system, as there are no private hospitals) can be visualized as a pyramid, with the JDWNRH at its apex. The system funnels patients from anywhere in the country who need specialized care to the JDWNRH, through the referral system. In addition, many patients self-refer, believing that they will receive superior care at the National Referral Hospital. The hospital also serves as the conduit for patients being transferred out of the country to receive more specialized care than they can obtain in Bhutan. In addition to its important national role, the hospital is the only major allopathic hospital in Thimphu district. (The Institute of Traditional Medicine Services provides traditional Bhutanese medical services and medicines, and two much smaller Indian hospitals also provide allopathic medical care.) As a result, the hospital delivers a very large proportion of the medical care available in Thimphu City and the surrounding areas.

Bhutan's geographic isolation means that the hospital will confront the immediate aftermath of a major earthquake without outside assistance. An earthquake that causes heavy damage in Thimphu is also likely to damage the area's only airport (at Paro) and to cause landslides that will block the roads into the city. Very large earthquakes will also cause significant damage in the neighboring states of India, which will hinder India's response and further disrupt transportation links to Bhutan. It is vital that the hospital be prepared and maintain the ability to function following an earthquake, when the community will need it most. The community will need the hospital not only to treat those injured by the earthquake, but also to provide for the urgent ongoing healthcare needs of the city.

In 2012, GHI performed an initial seismic vulnerability assessment of the JDWNRH. The goal of the assessment is to provide the hospital, the Ministry of Health, and SEARO with an overview of the hospital's seismic vulnerabilities and the recommended actions to improve the hospital's ability to deliver medical care following a major earthquake affecting Thimphu. This report summarizes the results of GHI's initial seismic vulnerability assessment.

Assessment Team and Methods

GHI's evaluation team consisted of Mr. William Holmes, Senior Consultant, Rutherford & Chekene Structural and Geotechnical Engineers of San Francisco, California, USA; Mr. Hari Kumar, GHI South Asia Regional Coordinator; Dr. Janise Rodgers, GHI Project Manager; Ms. Karma Doma Tshering, GHI Bhutan National Coordinator; and Mr. Sonam Tenzin, GHI Project Officer. The team has more than 65 combined years of experience in earthquake safety. Prior to its submission to SEARO, this report was reviewed by Dr. Dhrupthob Sonam, Medical Superintendent, JDWNRH; Mr. Wangdi Gyeltshen, Chief Engineer, Health Infrastructure Development Division; Dr. David Wald, Research Geophysicist, United States Geological Survey; and Mr. L. Thomas Tobin, President, Earthquake Engineering Research Institute and GHI Senior Advisor. Any inaccuracies are the responsibility of the report authors.

The evaluation team visited the hospital site multiple times, reviewed structural and architectural drawings, and interviewed the Medical Superintendent, Chief Engineer of the Health Infrastructure

Development Division (HIDD) and other key staff members. Team members conducted walk-through assessments of major medical service delivery areas inside the main hospital and Filter Clinic and equipment, and of services and support functions inside the Service Block, Bio-Medical Engineering Division (BMED) offices and HIDD offices. The team viewed all other buildings on the site from the exterior. The team obtained preliminary earthquake shaking estimates from the USGS and DGM. Estimates of damage to equipment were obtained using idealized relationships called *fragility functions* between the level of earthquake shaking and the level of damage; these fragility functions were developed for the Applied Technology Council's Report ATC-58-1 *Guidelines for Seismic Performance Assessment of Buildings*. The team did not conduct non-destructive testing, remove architectural finishes, conduct destructive evaluations or perform calculations. 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

This report includes an initial seismic assessment of the hospital's medical buildings (which comprise the main hospital building, filter clinic and old building), on-site utility infrastructure, community health buildings, staff quarters, on-site engineering and maintenance offices. The buildings and infrastructure belonging to the Royal Institute of Health Sciences (RIHS), University of Medical Sciences of Bhutan (UMSB) and private medical shops on the hospital grounds are outside the scope of this report. Some smaller buildings, such as storage sheds, on the hospital campus are likewise excluded from the scope of this report. Evaluations of the site's many retaining walls are outside the scope of this initial assessment.

The scope of the assessment did not include any evaluation of potential earthquake vulnerabilities of the off-site electrical power, water, land-line telephone, mobile telephone, wastewater and solid waste disposal utilities that serve the hospital, nor of the time required to restore service following an earthquake. Similarly, evaluation of transportation systems and access routes to the hospital was beyond the scope of this report.

Hospital Facility Description

The hospital was established in 1972 as a general hospital. In 1994, the hospital added new services and was renamed in honor of the third Druk Gyalpo, His late Majesty Jigme Dorji Wangchuck. A new 350-bed hospital building was inaugurated in December 2008. The hospital's buildings, which include medical buildings, staff residences, offices and support buildings, have been built over time. Major phases of hospital construction include the 1980s; the late 1990s, when the filter clinic (which contains mainly outpatient services) and some staff quarters were built; and 2004-2009, when the current main 350-bed hospital building, service block and parking garage were built.

Buildings

The main 350-bed hospital is a ground plus five storey building, built from reinforced concrete frames with brick masonry infill walls and partitions. The service block is ground plus two stories, and is also built with reinforced concrete frames and brick masonry infill walls and partitions. A reinforced concrete pedestrian and utility services bridge connects the two buildings. The buildings have some traditional

Bhutanese architectural features on their exterior, despite having been built with modern materials. The two-level reinforced concrete parking garage is directly adjacent to the hospital. The ambulance entry for the emergency department is located on one side of the parking garage's upper level.

The older buildings that were used for acute care prior to construction of the new hospital building are now being used as a filter clinic providing outpatient services, for support functions, for community health programs, and for the Health Help Center (Bhutan's emergency medical call center). These are primarily single to ground plus two storey reinforced concrete frame buildings with masonry infill walls, but some buildings used by the community health department are unreinforced masonry. The Health Help Center occupies an unreinforced brick building. One older building was turned over to UMSB and is outside the scope of this report. The site also contains numerous staff residences, ranging from single storey to ground plus two storeys, built either of unreinforced masonry or reinforced concrete frame with masonry infill. The site plan in Figure 1 below shows the hospital's buildings, color coded by use.

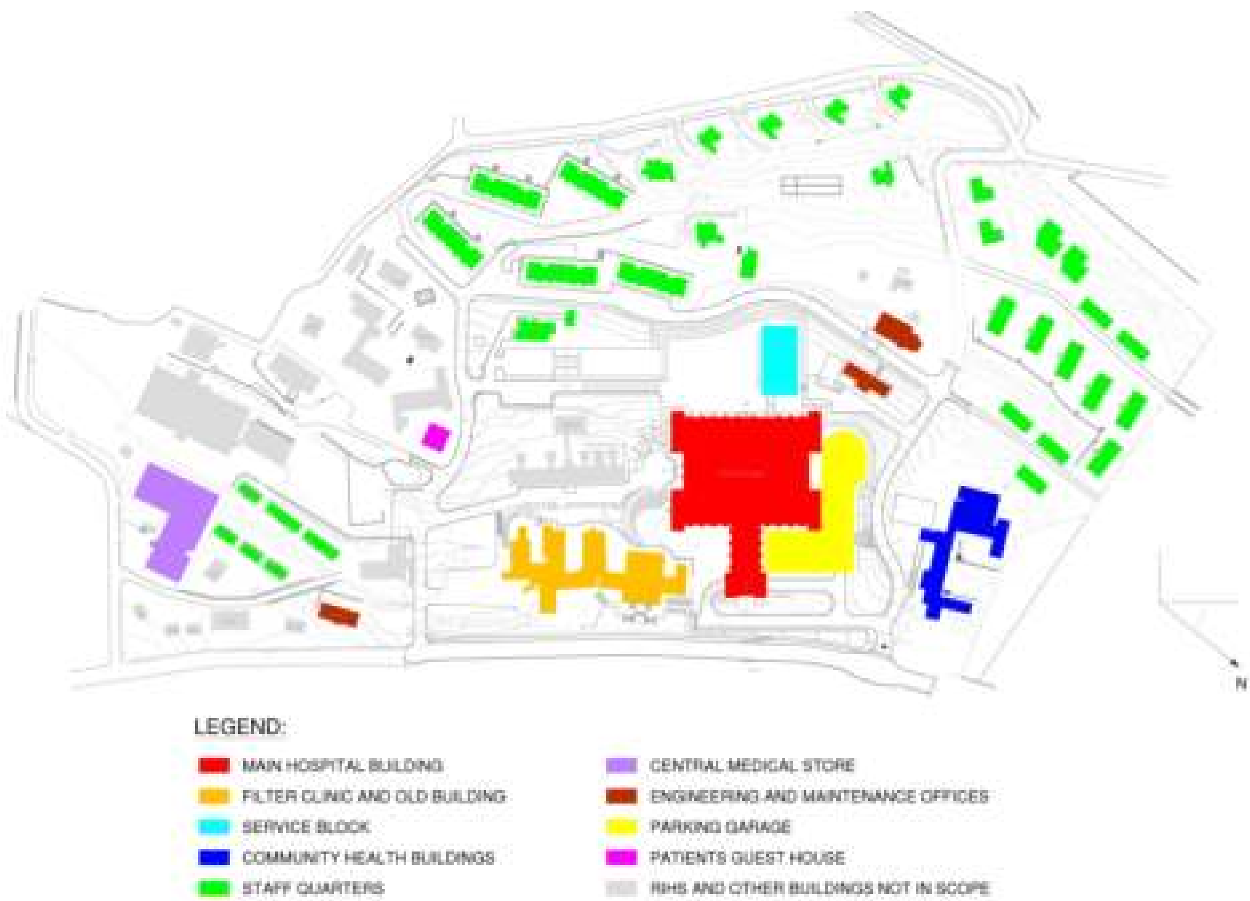


Figure 1. Site plan with buildings color-coded by use

Infrastructure and Utility Services

The hospital's electric power supply comes from the local grid. Three 750 kVA (600 kW) diesel generators provide backup power, with two generators being capable of supplying power to the hospital building's essential services such as the ICU, Operation Theatres and dialysis unit. Diesel fuel for the generators is brought in drums by truck and stored in 990L storage tanks located adjacent to the generators. When running, each generator consumes approximately 60L of diesel fuel per hour.

City water supply from two sources feeds a 1,000,000L reinforced concrete tank on the hill above the main hospital building. The tank is partitioned into a 200,000L section for fire-fighting and an 800,000L section for domestic water supply. Incoming city water has received only basic treatment (the team assumed primary treatment only), so the hospital has installed numerous water filters in wards and other areas to provide drinking water. These filters rely on electricity to function. Three electric boilers provide steam for heat, while one electric hot water generator supplies hot water. Each block has an air handling unit connected to the main boiler system. The hospital relies on the city sewer system for wastewater disposal and treatment. Medical waste is autoclaved before being sent to the municipal disposal, except for human organs, which are disposed of in a deep burial pit in the hospital compound.

Medical gas is supplied via cylinders that are brought in by a supply company truck from Phuentsholing in approximately 120-cylinder shipments three times per week. The hospital does not have a bulk oxygen tank. Most of the hospital's medical supplies are kept at the Central Medical Store, which is under the Drugs Vaccine and Equipment Division (DVED), Department of Medical Services, of the Ministry of Health rather than the hospital itself. The Central Medical Store is located on the southeast side of the RIHS and is not accessible by vehicle directly from the hospital campus. The Central Medical Store is accessed from a separate road that runs behind Changzamtok Middle Secondary School, but it is less than one kilometer from the hospital by road. The CMS receives a year's worth of supplies, plus a ten percent buffer (i.e., more than one month's supply), during the period from October to January. Supplies arrive in the Central Medical Store by truck from the Ministry of Health Medical Supply Depot in Phuentsholing. As a result, early in the year the hospital has a large amount of supplies on hand, but the surplus decreases steadily throughout the year. The hospital has pharmacies for inpatients and outpatients, but these keep limited supplies on hand.

Location and Site Conditions

The hospital is located on a moderate slope in the Changzamtok area of South Thimphu. Figure 2 shows the hospital's location. The hospital sits on an alluvial fan formed by streams eroding the mountains behind it, as Figure 3 shows.

Figure 2. Hospital location (denoted by red placemark) in Thimphu

Figure 3. Topography near the hospital (pale yellow building in foreground); note large retaining wall in front of hospital

Geotechnical reports were not available for either the hospital itself or a newly constructed building for the Royal Institute of Health Sciences, located on the south side of the campus. Structural drawings were not available for the site's many retaining walls, including the large retaining walls at the front and rear of the main hospital building. The large retaining walls, some of which are shown in Figure 4, must be evaluated, because instability would threaten the hospital's ability to function. These walls may be unreinforced stone masonry and if so, could be highly vulnerable to earthquake damage.

Figure 4. Retaining wall behind the Service Block (left); pipes emerging from the same retaining wall (right)

The evaluation team understands that no portion of the hospital was built on fill. If portions of any building have been built on fill, then those fills could be susceptible to differential settlement during an earthquake, possibly causing additional damage to that which is described in this report. The evaluation team did not investigate the adequacy of drainage and stormwater management at the site, but these should be assessed. The site does not contain creeks or streams, though there may be a small stream on the south side of the Royal Institute of Health Sciences. The team recommends that any detailed evaluation include a thorough investigation of the site's geotechnical conditions, including any fills if present, as well as drainage conditions and the major retaining walls.

Earthquake Hazard

Bhutan is located in the Himalayas, where damaging earthquakes occur frequently. While the earthquake hazard has not been well-studied locally and no seismic instruments are currently operating in the country, recent studies indicate that Bhutan faces a very high level of earthquake hazard. The main fault that delineates the boundary between the Indian and Eurasian plates approximately parallels Bhutan's southern border. This fault is a thrust fault that dips under Bhutan at a shallow angle, meaning that the fault plane extends underneath the entire country. Bhutan lies in the seismic gap between the 1934 Bihar-Nepal earthquake and the 1950 Assam earthquake, and paleoseismic studies (in which geologists dig trenches across active faults and determine when major fault movements occurred using radio-carbon dating) indicate that a very large earthquake last occurred on this section of the plate boundary in approximately 1100 AD[1]. Scientists estimate that this earthquake had a magnitude of 8 or greater. If a similarly sized earthquake were to occur today, then the damage would likely be severe throughout Bhutan.

While numerous earthquakes of different magnitudes in varied locations could affect Thimphu, the evaluation team selected three hypothetical earthquakes as examples to illustrate the range of shaking, damage and resulting consequences that the hospital is likely to experience in a damaging earthquake:

1. A moderate earthquake of approximately magnitude 6 (M6), which is roughly the size of the 2009 Mongar earthquake, occurring close to Thimphu;
2. A major earthquake of M7 occurring close to Thimphu; and
3. A massive earthquake of M8.6 occurring on the plate boundary.

These hypothetical earthquakes may not be the three most likely events, nor are they necessarily the three most potentially damaging events. However, although varying in magnitude, they are all located close to the hospital site, which will produce more intense shaking than similarly-sized events located farther away. For the purposes of this report, all three of these hypothetical earthquakes were assumed to occur on the main plate boundary fault that underlies Bhutan. The USGS, with collaboration from University of Indiana and DGM, provided preliminary estimates of the median levels of ground shaking that these three hypothetical earthquakes might cause. USGS used its ShakeMap software, with University of Indiana providing input parameters describing the hypothetical fault ruptures, and DGM providing input on the plausibility of each earthquake.

Please note that the USGS estimates of potential shaking contain large uncertainties, because the scientific community's understanding of Bhutan's earthquake hazard is still emerging. Bhutan's active faults have not been mapped; no local seismometers record earthquake shaking; scientific relationships that describe how ground shaking may vary with Bhutan's geology have not been formulated. The estimates of potential shaking presented in this report are for purposes of illustration only and should not be used for engineering design. The estimates consider only approximate, generalized site conditions; local site effects could further affect the amplitude and nature of ground shaking, and should always be included when developing site-specific estimates of shaking for engineering design. The estimates presented in this report may be used for emergency planning, with appropriate precautions taken to account for the uncertainties involved.

A subsequent section of the report, entitled "Hospital Impact Scenarios for Three Hypothetical Earthquakes," provides more details on the hypothetical scenario earthquakes and the hospital's postulated response to them.

[1] Kumar, S. Wesnousky, S.G., Jayangondaperumal, R., Nakata, T., Kumahara, Y. and V. Singh (2010). Evidence for surface rupture along the northeastern Himalayan front, India: Timing, size, and spatial extent of great earthquakes. Journal of Geophysical Research, 115 (B12422), 1-20.

Observed Earthquake Vulnerabilities

Collapsing buildings cause the majority of deaths in most earthquakes. Determining whether or not buildings are vulnerable to major structural damage or collapse, which would put lives at risk, is the first and most important task in a vulnerability assessment. For hospitals, the ability to remain functional is also critically important, both to preserve the lives of patients and to save the lives of those injured in the earthquake throughout the region. Vulnerabilities in the facility's utility systems, architectural shell, equipment and contents all affect the hospital's ability to function. The team assessed the hospital facility for all of these vulnerabilities.

The assessment team used engineering judgment and observations of damage to reinforced concrete and masonry buildings in previous earthquakes to estimate the potential levels of damage to the hospital's buildings during the three scenario earthquakes described in the Earthquake Hazard section above. The team classified damage to the building's structure and architectural shell (the exterior walls, roof covering and interior partitions), and to the building's equipment and contents into the states listed in Table 1. It is important to note that building usability does not equal functionality: the hospital will be functional only if critical utility services, such as electrical power, are available. Without utilities, the building could only be used to deliver a very basic level of "austere" care. Because of the importance of utilities, the team has estimated whether or not each of the hospital's major utility systems will be available following the three hypothetical scenario earthquakes.

Table 1. Damage state classifications

Structure and Architectural Shell[1]		
Damage State	**Life Safety Risk**	**Building Usability[2]**
S1 Slight	Very slight	Building is useable based on structural performance
S2 Moderate	Isolated falling hazards	Useable with clean up required, possibly some areas condoned off. A few partitions may be cracked and/or have pieces fallen
S3 Heavy	Significant falling hazards	Widespread masonry falls from partitions and/or bearing walls disrupt function
S4 Severe/Collapse	Severe from falling hazards or partial/complete collapse	Building has not maintained usable spaces or is unsafe
Equipment, Pipes and Contents[3]		
Damage State		**Building Usability[2]**
N1 Light		Building is useable
N2 Moderate disruption		Generally useable; some areas may be cordoned off, and some medical functionality may be lost
N3 Severe disruption		The building in general is so disrupted that it will be hard to use without a lot of cleanup and repair

1 Includes the building's walls, frame (if a reinforced concrete building), masonry partitions, floors, roof and roof covering.
2 Building usability does not equal functionality. The hospital will be functional only if critical utility services, such as electrical power, are available.
3 Only assessed in main hospital building, Service Block, Filter Clinic and Old Building, Central Medical Store and Health Help Center

Each damage state for the structure and architectural shell has corresponding implications for both life safety and building usability. Likewise, each damage state for the equipment, pipes and conduits, and contents inside the building has implications for building usability. In some cases (i.e. tall and heavy shelving located behind or above staff work areas), each damage state for contents may also have implications for life safety, but these must be evaluated on a case-by-case basis.

Vulnerability of Buildings to Structural Damage

The hospital's buildings are predominantly of two construction types: reinforced concrete frame with unreinforced masonry infill walls, and masonry bearing wall. Both types of buildings tend to suffer major, life threatening damage in strong earthquakes, unless an engineer has designed them following a modern, earthquake-resistant building code that specifically covers these building types. Based on a review of structural drawings and on discussions with Health Infrastructure Development Division engineers, it appears that only the hospital's newest buildings (the reinforced concrete frame buildings designed after 1993) were designed using modern earthquake-resistant building codes developed in India, albeit at least one version older than the current version. As a result, buildings at the hospital site can be expected to experience various levels of damage in moderate to strong earthquakes.

Using the three hypothetical scenario earthquakes as illustrative examples of moderate, major and severe earthquakes, this report presents the likely performance for each building in tables in the sub-sections below. The team used engineering judgment, based on experience with buildings of these construction types in other earthquakes, to determine the estimated levels of damage. In addition to the buildings discussed in this section, the hospital has various smaller unoccupied buildings and some small timber cabin staff quarters. These were not considered within the scope of this assessment.

In some cases, it was difficult to determine the building's structural system conclusively, because of the exterior finishes and lack of drawings. In those cases, the team assumed the more seismically vulnerable of the (generally two) possible structural systems. It should be noted that for the types of buildings at the hospital site, uncertainties regarding the type of masonry do not have a large effect on the building's potential damage level. Unreinforced masonry buildings built without *seismic bands* (horizontal reinforced concrete members embedded in the walls to tie them together) and similar earthquake-resistant features are inherently unsafe in strong earthquakes, whether the masonry is stone, brick or concrete block.

Prior to discussing specific buildings in the sub-sections below, several general observations are warranted about the codes and standards used for the structural design of the hospital's buildings.

Building Codes Used for Design

Bhutan adopted its own seismic design provisions, which are based on the Indian Standard provisions, in 1996. Prior to this, engineers often used the Indian Standards. The current version of India's earthquake-resistant design code (IS 1893 – *Criteria for Earthquake Resistant Design of Structures*) was released in 2002 and includes modifications made after the 2001 Gujarat earthquake. All of the hospital's buildings were designed prior to the 2002 code revision, even if they were built more recently. India also has a standard for ductile detailing in reinforced concrete buildings, IS 13920 (*Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces – Code of Practice*), which was released in 1993 and has been reaffirmed (rather than revised) in following years.

Consequently, the team assumed that reinforced concrete buildings designed prior to 1993 do not have the ductile details necessary for earthquake resistance. Structural drawings were available only for the main hospital building, service block and the L-shaped nurses' quarters. It is possible that some of the buildings built in the early 1990s could have ductile detailing, if the design engineer used another ductile detailing standard (e.g., the American Concrete Institute's ACI-318 *Building Code Requirements for Structural Concrete*), but that is unlikely, and field verification of earthquake-resistant details would be required. Reinforced concrete buildings designed prior to 1976, when minimal ductile detailing requirements first appeared in the Indian Standards (in IS 4326:1976, *Code of Practice for Earthquake Resistant Design and Construction of Buildings*), will not have earthquake-resistant detailing.

India also has a standard, IS 4326 (*Earthquake Resistant Design and Construction of Buildings —Code of Practice*), intended to improve the earthquake resistance of masonry bearing wall buildings. This standard was released in 1993 and most recently updated in 2002. The standard mandates that masonry buildings in high seismic hazard zones have vertical bars in the corners and reinforced concrete bands to promote "box" action (where the building's walls act together, like a box, to resist earthquake forces) and to help the walls span horizontally between cross walls. Removing building finishes, which is required to determine definitively whether or not plastered masonry buildings have IS 4326-prescribed earthquake-resistant features, was outside the scope of this assessment. The team assumed that the masonry buildings at the site did not incorporate the IS 4326-prescribed seismic bands and vertical bars. The postulated seismic performance of unreinforced masonry buildings will improve, if field investigations verify the presence of seismic bands and/or bars.

Main 350-bed Hospital Building

The main hospital building, shown in Figure 5, was built with funding from the Government of India. Construction began in 2005, and the building was inaugurated in December 2008 and entirely finished in early 2009. Indian architects and engineers working for a private hospital development corporation designed the hospital building, along with the associated Service Block and connecting bridge shown in Figure 6, presumably to meet the Indian Standards. The structural system is a reinforced concrete moment frame, in which rigid joints between beams and columns resist forces. The design includes all columns and all beams in both directions as part of the moment frame, which enhances the earthquake performance. The frame was designed with ductile details that appear to meet IS 13920 (*Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces – Code of Practice*); however, the design was completed in 2001, and the version of the earthquake-resistant design code IS 1893 that would have been used does not contain the modifications made after the 2001 Gujarat earthquake. The building has clay brick infill walls and single wythe (i.e., built from a single row of bricks) brick partitions.

Figure 5. Exterior view of new Main Hospital Building showing parking garage (lower foreground), main entry (left) and ambulance entry for emergency department (right). Note captive columns (see page 20) caused by partial height masonry walls and decorative Zhu in parking garage.

Figure 6. Rear view of Main Hospital building showing location of Service Block (at left) and connecting bridge (center)

While the building appears highly irregular in plan, it consists of eight relatively regularly shaped blocks (Blocks A-G, plus a core) separated by seismic joints, as Figure 7 (following page) shows. Per the Indian Standards, these joints should be 100mm. The building has a steel roof truss covered by corrugated metal roofing. At the roof levels, there are concrete beams in both directions below the roof trusses, but no concrete slabs that would act as a diaphragm (a horizontal structural member that distributes earthquake forces to the building's frames and/or walls).

Table 2 on page 19 summarizes the damage states (defined in Table 1) for the main hospital building's blocks and the parking garage. The building is not likely to suffer significant life-threatening structural damage in any of the three hypothetical scenario earthquakes being used for discussion purposes in this report. The building's brick infill walls and partitions will tend to crack, when any floor in the building moves horizontally more than 1% of the floor-to-floor height, and partitions are likely to fail during strong shaking. Although not so serious as a partial structural collapse, such failures could cause serious injuries, particularly to immobile patients. Determining the level of earthquake shaking at which such cracking would occur requires a detailed computer analysis, which is beyond the assessment's scope.

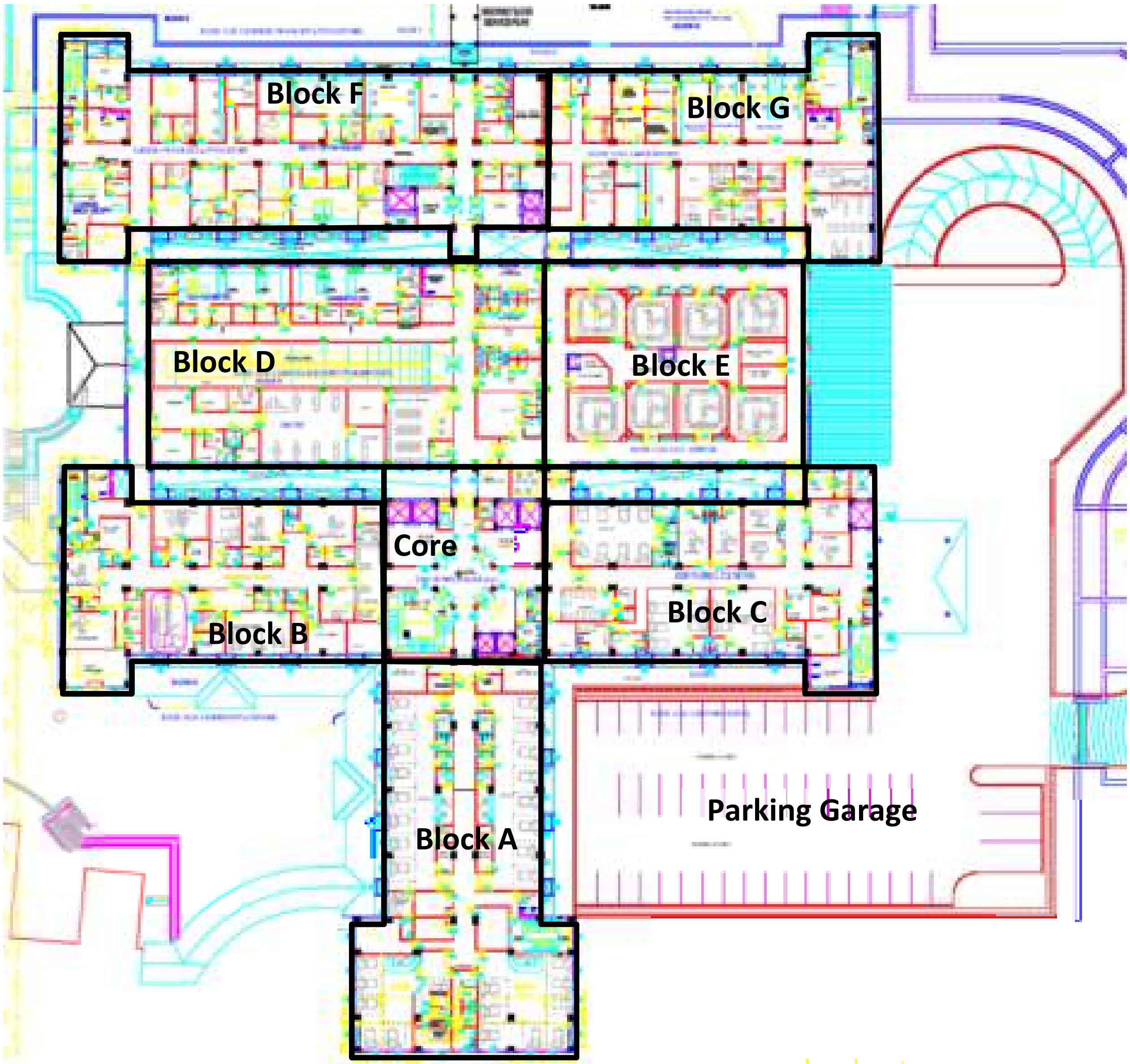


Figure 7. Plan of main hospital building showing Blocks A-G

Damage to partitions and infill walls, along with isolated partition failures (most likely in the upper storeys), as well as some minor damage to the reinforced concrete frame may begin to occur in an earthquake the size of the M7 hypothetical scenario earthquake. In the M8.6 hypothetical scenario earthquake, the main building's concrete frame may experience damage at the ends of beams, and the brick infill walls are likely to suffer heavy damage, but the building should retain its structural integrity and be able to resist a strong aftershock without collapse. At such strong levels of shaking, many partition walls built from a single wythe of bricks are likely to collapse. Bricks from these walls would be falling hazards that could endanger people nearby and inhibit function of the adjacent spaces. Extensive cracking in the brick infill walls and partitions are likely to cause occupants to question the safety of the building. People may not want to stay in or use the building, and the building could become effectively non-functional as a result.

Table 2. Likely performance of main hospital building Blocks A-G and parking garage in hypothetical scenario earthquakes

Building Name	**Construction Type**	**Year Built**	**No. of Stories (incl. ground)**	**Likely Performance in Hypothetical Scenario Earthquake**[1] (Structure and shell: left columns; equipment, pipes contents: right columns)					
				Moderate M6.1		Major M7		Severe M8.6	
				PGA 0.25g		PGA 0.58g		PGA 1g	
				Struct	Equip	Struct	Equip	Struct	Equip
New Main Hospital									
Block A	RC w/brick infill	2008	5	S1	N1	S2	N2	S3	N3
Block B	RC w/brick infill	2008	6	S1	N1	S2	N2	S3	N3
Core	RC w/brick infill	2008	6	S1	N1	S2	N2	S3	N3
Block C	RC w/brick infill	2008	6	S1	N1	S2	N2	S3	N3
Block D - Ramp	RC w/brick infill	2008	5	S1	N1	S3	N2	S3	N3
Block E	RC w/brick infill	2008	3	S1	N1	S2	N2	S3	N3
Block F	RC w/brick infill	2008	6	S1	N1	S2	N2	S3	N3
Block G	RC w/brick infill	2008	6	S1	N1	S2	N2	S3	N3
Parking Garage	RC frame	2008	1	S1	n/a	S3	n/a	S4	n/a

1 Damage states are defined in Table 1

Block D contains a large ramp structure for moving patients between floors. Although such ramps are a good design feature for post-earthquake movement of patients, they are also stiff elements that are likely to act as braces. As a result, they will experience significant earthquake forces (because they are stiffer than the moment frames, and the building will “push” against the ramps first), though they were not intended to do so. The ramp may suffer heavy damage, and Block D is likely to suffer more damage than the other blocks as a result. The ramps also intersect some columns at mid-height, which is likely to damage the columns by imposing large earthquake forces and deformations that the structural engineer did not design for. The reinforced concrete stairs are fixed to floors at both ends, and will tend to act as braces and experience large earthquake forces for reasons similar to those described above. Infill falling into the stairwells may partially or completely block the stairs, and the stairs themselves may fail. The stair towers have solid infill walls that also stiffen the frame. The towers’ locations at the outer ends of Blocks B, C, F and G may create earthquake force imbalances within the building that cause some additional damage. Damage to the ramps and stairs will greatly reduce the staff’s ability to move patients between floors after the earthquake, especially if the lifts are damaged and the power is out.

Under strong earthquake shaking, the blocks may undergo enough deformation to begin to pound against one another. There may be more relative movement between Block D, which contains the ramps, and the adjacent blocks. Because the floor slabs are aligned, pounding should not cause life-threatening structural damage, but it might cause higher accelerations in the floor slabs that could damage acceleration-sensitive medical equipment. However, any utility service pipes or conduits crossing the seismic joints are likely to be damaged by the relative motion of the blocks, unless flexible connectors that can accommodate the expected deformation have been provided. It will be necessary to verify that these flexible connectors exist; the evaluation team was not able to access these areas. Fire sprinkler lines shown on the drawings cross the seismic joints at multiple locations. Broken fire sprinkler pipes can cause significant water damage and severely impede function.

The parking structure has what structural engineers call *captive columns* or short columns, where stiff partial height masonry walls and the decorative *Zhu* at the tops of columns impede the columns' ability to move back and forth during an earthquake. Numerous past earthquakes have shown that buildings with captive columns are prone to major damage and collapse. These columns are likely to suffer heavy damage in the M7 and M8.6 hypothetical scenario earthquakes. Local collapse of these columns in the outer bay of the parking structure is possible in the M8.6 hypothetical scenario earthquake.

Service Block

The Service Block, shown in Figure 8, was designed and built at the same time as the main hospital building. It is a ground plus two storey reinforced concrete moment frame building with unreinforced brick masonry infill walls two wythes thick. The ground storey, which is much taller than the upper two, contains equipment for the hospital's backup electrical system, medical gas system, heat and hot water systems, as well as the laundry facilities. The first floor contains the hospital kitchen, and the second floor contains the pharmacy for inpatients, plus some offices.

Figure 8. Exterior view of Service Block taken from top of retaining wall behind hospital, showing tanks for vacuum (blue) and empty medical gas cylinders awaiting pickup. Bridge to main hospital is at right.

The taller ground storey with relatively fewer columns, which is necessary to accommodate large mechanical equipment, makes the building seismically vulnerable. This storey is more flexible than the storeys above it are, and earthquake-imposed deformations and damage will tend to concentrate in this storey. Table 3 shows the likely performance of the Service Block in three hypothetical scenario earthquakes, which illustrate a range of damaging earthquakes the hospital might experience.

Table 3. Likely performance of the Service Block in hypothetical scenario earthquakes

Building Name	**Construction Type**	**Year Built**	**No. of Stories (incl. ground)**	**Likely Performance in Hypothetical Scenario Earthquake** (Structure and shell: left columns; equipment, pipes contents: right columns)					
				Moderate M6.1		Major M7		Severe M8.6	
				PGA 0.25g		PGA 0.58g		PGA 1g	
				Struct	Equip	Struct	Equip	Struct	Equip
Service Block/pharmacy	RC w/brick infill	2008	3	S1	N2	S2	N2	S3-S4	N3

Bridge between Main Hospital Building and Service Block

The Service Block connects to the main hospital building via an L-shaped, ground plus one storey reinforced concrete pedestrian and utility services bridge, shown in Figure 9. The bridge's pedestrian walkway connects the hospital's wards to the kitchen and pharmacy, which are located in the first and second storey of the Service Block. Pipes for medical gas and conduits for electricity are suspended from the underside of the pedestrian walkway.

Figure 9. Bridge connecting Service Block to main hospital building (left); conduits and pipes suspended from walkway (right)

The ground storey of the bridge is significantly taller than its first storey. Though the drawings show extensive measures to seismically separate the bridge from the main building and Service Block, these measures may not have been implemented when the bridge was built. As a result, the bridge may interact with the buildings during an earthquake. Table 4 shows the likely performance of the bridge in the three hypothetical scenario earthquakes considered in this report.

Table 4. Likely performance of bridge connecting main hospital building and Service Block in hypothetical scenario earthquakes

Building Name	**Construction Type**	**Year Built**	**No. of Stories (incl. ground)**	**Likely Performance in Hypothetical Scenario Earthquake** (Structure and shell: left columns; equipment, pipes contents: right columns)					
				Moderate M6.1		Major M7		Severe M8.6	
				PGA 0.25g		PGA 0.58g		PGA 1g	
				Struct	Equip	Struct	Equip	Struct	Equip
Bridge from Service Block to Main Bldg.	RC frame	2008	2	S1	N1**	S1	N2-N3**	S2	N3**

** Pipes and services at joints

Filter Clinic and Old Building

The Filter Clinic and the Old Building were built at different times but are connected by a passageway. Each building is described in detail in the sub-sections below. Table 5 shows the team's estimate of potential damage to the Filter Clinic and the Old Building in each of the three hypothetical scenario earthquakes.

Table 5. Likely performance of Filter Clinic and Old Building in hypothetical scenario earthquakes

Building Name	**Construction Type**	**Year Built**	**No. of Stories (incl. ground)**	**Likely Performance in Hypothetical Scenario Earthquake** (Structure and shell: left columns; equipment, pipes contents: right columns)					
				Moderate M6.1		Major M7		Severe M8.6	
				PGA 0.25g		PGA 0.58g		PGA 1g	
				Struct	Equip	Struct	Equip	Struct	Equip
Filter Clinic and Old Bldg.									
Filter Clinic	RC w/brick infill	1997	3	S1	N1	S2	N2	S3	N3
Old Building main	Nonductile RC w/brick infill	1972 or later	2	S2	N1	S3	N2	S3-S4	N3
Old Building rear addn	Mixed*	1980s	2	S2	N2	S3	N2	S3-S4	N3

RC = reinforced concrete; URM = unreinforced masonry
* Exact construction material type and details are not known; assumed type is the most vulnerable of the likely construction material/structural system types. Vulnerability rating may improve if better, more earthquake-resistant construction can be verified.

Filter Clinic

The Filter Clinic building was completed in 1997 as part of a planned expansion of the hospital. This building, shown in Figure 10 (following page), houses the administrative offices and some outpatient departments (OPDs). The building has reinforced concrete moment frames with masonry infill walls. The central portion of the building is ground plus two storeys; the side wings are ground plus one storey.

Figure 10. Front view (left) showing columns supporting overhang; and rear view (right) of Filter Clinic building

The evaluation team presumed that the building was designed to meet the prior version of Indian Standards IS 1893 (for earthquake-resistant design) and IS 13920 (for ductile detailing of reinforced concrete). Neither structural nor architectural drawings were available. The columns supporting the bays overhanging the entrance are potentially vulnerable, because the lack of masonry infill makes the columns more flexible and may encourage damage to concentrate there. The columns also have decorative *Zhu* at the top, which will likely confine the top of the column and force damage to occur lower in the column than the design engineer intended, in a section that is not adequately reinforced.

Old Building

The oldest portions of the hospital's medical buildings include the hospital's old main building, which may have been completed as early as 1972, plus additions that may have been built in the 1980s. The building houses the pediatric OPD, pediatric physiotherapy, rehydration unit, forensic department, public health laboratory, plus the hospital conference hall, canteen, and library and an office for the newly formed UMSB. No structural or architectural drawings are available for the building or additions. The oldest portions, painted dark gray at the time of this report and shown in Figure 11 (following page), appear to be concrete frames built without ductile detailing. The building has captive columns, which are prone to major damage and collapse.

Figure 12 (following page) shows the two wings added to the rear of the building over time, likely beginning as early as the late 1970s. The wing closest to the main hospital (left photo) is a reinforced concrete frame building with masonry infill walls. The second wing appears to be mixed construction built over time, with a reinforced concrete frame in the ground storey and a timber upper storey, and a single-storey, irregular-in-plan unreinforced masonry wrap-around addition on the back and side.

Figure 11. Front and side views of old part of Filter Clinic building (Old Building)

Figure 12. Rear exterior views of old part of filter clinic building, showing additions

Community Health Buildings

The hospital provides various community health services in a complex of older buildings located to the north of the new main hospital building. These services include ante- and post-natal care, immunizations, family planning, physiotherapy, tuberculosis testing and care, voluntary counseling and treatment and mental health. The Health Help Center, which is the nationwide call center for emergency medical response, is located in this complex but will be described in a separate section below. The largest of these older buildings once housed the pediatric wards. Some smaller, mostly unreinforced brick or block masonry buildings step down the hillside towards the larger Psychiatric Ward. The buildings were apparently built in the 1980s, but some may date from the 1970s. The ages of these buildings were particularly uncertain.

Table 6 provides information assumed on the buildings' construction types and ages, plus estimated damage states in the hypothetical scenario earthquakes.

Table 6. Likely damage states for community health buildings in hypothetical scenario earthquakes

Building Name	Construction Type	Year Built	No. of Stories (incl. ground)	Likely Performance in Hypothetical Scenario Earthquake		
				Moderate M6.1	Major M7	Severe M8.6
				PGA 0.25g	PGA 0.58g	PGA 1g
Community Heath						
Old Pediatric Ward	Nonductile RC w/infill	1980s	2	S1-S2	S2	S3
Upper L-shaped bldg.	URM*	2000s	1	S2	S3	S4
Hand Therapy Clinic	URM*	1980s	1	S2	S3	S4
TB and vol. testing bldg.	URM*	1980s	1	S2	S3	S4
Psychiatric Ward (front)	URM*	1980s	1	S2	S3	S4
Psychiatric Ward (rear)	Nonductile RC w/infill	1980s	2	S2	S3	S3-S4

RC = reinforced concrete; URM = unreinforced masonry
* Exact construction material type and details are not known; assumed type is the most vulnerable of the likely construction material/structural system types. Vulnerability rating may improve if better, more earthquake-resistant construction can be verified.

Main Community Health Buildings (Old Pediatric Ward)

The main community health buildings are interconnected ground plus one storey reinforced concrete frame buildings with unreinforced brick or block infill walls, as shown in Figure 13 below. The frames appear to be complete frames (meaning they all have beams and columns), but as Figure 14 (following page) shows, the building has a very irregular and complex configuration, especially on the entrance side facing the main hospital. Short columns exist in some locations. The buildings were likely built prior to India's adoption of a modern ductile detailing code in 1993, which would mean they lack earthquake-resistant ductile details and are thus more vulnerable to earthquake damage. A more recently constructed L-shaped building (which does not appear on a 2002 site plan) on the west side of the main complex (far left of Figure 13) appears to be unreinforced masonry.

Figure 13. Overall view of main complex of community health buildings

Figure 14. Views of back side of main community health buildings showing complex configuration

Hand Therapy Clinic and Tuberculosis Unit/Voluntary Testing Buildings

The Hand Therapy and Splinting Clinic, part of Physiotherapy, occupies the upper of two buildings that appear to be unreinforced masonry construction and that step down the slope below the main community health buildings, as Figure 15 shows. The lower of the two buildings houses the Tuberculosis Unit and the Voluntary Counseling and Testing Unit.

Figure 15. Front (left) and rear (right) views of Hand Therapy Clinic and TB Unit and Voluntary Testing Unit Building

Psychiatric Ward

The Psychiatric Ward consists of two buildings shown in Figure 16 (following page): a single storey building in front that appears to be unreinforced masonry, and a ground plus one storey reinforced concrete frame building with either unreinforced brick or concrete block infill walls. The buildings are at the downhill end of the group of community health buildings, immediately down of and adjacent to the Health Help Center. The reinforced concrete frame building, the side of which can be seen in the right-hand photo in Figure 15, has captive columns created by partial height infill walls below the windows. The reinforced concrete frame building may have been built at about the same time as the old pediatric ward building located uphill. The evaluation team understands that the Psychiatric Ward plans to move to a new building in a location 25km from Thimphu during the upcoming 11th Five Year Plan.

Figure 16. Psychiatric ward buildings

Health Help Center

The Health Help Center, Bhutan's national emergency medical call center, is housed in a brick masonry building originally built as a hostel for the RIHS in the 1970s. Unreinforced brick buildings typically perform poorly in earthquakes. The team understands that the current location is intended to be temporary, until the center can move to a new building. The current building is located between the Psychiatric Ward and the building that houses the Tuberculosis Unit. The building also has unanchored equipment, including a server, which could topple in an earthquake and suffer damage. Table 7 shows the likely performance of the Health Help Center's buildings and equipment in the hypothetical scenario earthquakes. Figure 17 (following page) shows the building and unanchored server equipment.

Table 7. Likely performance of Health Help Center in hypothetical scenario earthquakes

Building Name	**Construction Type**	**Year Built**	**No. of Stories (incl. ground)**	**Likely Performance in Hypothetical Scenario Earthquake** (Structure and shell: left columns; equipment, pipes contents: right columns)					
				Moderate M6.1		Major M7		Severe M8.6	
				PGA 0.25g		PGA 0.58g		PGA 1g	
				Struct	Equip	Struct	Equip	Struct	Equip
Health Help Center	URM	1970s	1	S2	N2	S3	N3	S4	N3

Figure 17. Health Help Center building (left); unanchored servers for the 112 emergency system (right)

Engineering and Maintenance Office Buildings

The organizations responsible for engineering design, maintenance and repair of medical equipment all have offices on the hospital site: these are the Health Infrastructure Development Division (HIDD), the hospital's Maintenance Division and the Bio-Medical Engineering Division. Following an earthquake, their presence on-site will facilitate inspections and repairs. Table 8 shows the likely performance of the engineering and maintenance office buildings in the hypothetical scenario earthquakes.

Table 8. Likely damage states for engineering and maintenance office buildings in hypothetical scenario earthquakes

Building Name	Construction Type	Year Built	No. of Stories (incl. ground)	Likely Performance in Hypothetical Scenario Earthquake		
				Moderate M6.1	Major M7	Severe M8.6
				PGA 0.25g	PGA 0.58g	PGA 1g
HIDD Office	URM*	1980s	1	S2	S3	S4
Maintenance Office	RC w/brick infill	1980s	2	S2	S2	S3
BMED Office	RC w/brick infill	1980s	1	S2	S2	S3

RC = reinforced concrete; URM = unreinforced masonry
* Exact construction material type and details are not known; assumed type is the most vulnerable of the likely construction material/structural system types. Vulnerability rating may improve if better, more earthquake-resistant construction can be verified.

Health Infrastructure Development Division (HIDD) Office

The Health Infrastructure Development Division is responsible for designing health facilities throughout Bhutan. Following a damaging earthquake, HIDD structural engineers will need to make safety and damage assessments of the hospital buildings and other health facilities. The HIDD office building, shown in Figure 18 (following page), appears to be unreinforced masonry, probably brick. The configuration is approximately an "L" shape, with irregularities in plan. The building has a painted band at the lintel level, but this band is assumed to be an architectural decoration. The evaluation team understands that the building was not built in accordance with Indian Standard IS 4326 and therefore lacks earthquake-resistant features such as seismic bands. The building has single wythe brick partitions that are likely to collapse during strong earthquake shaking.

Figure 18. Front (left) and side (right) views of HIDD office

Maintenance Office

The Maintenance Division's office building, shown in Figure 19, is a ground plus one storey reinforced concrete frame building with unreinforced masonry infill. There are no columns along the window line, only along the corridor. The building has few infill walls in the longitudinal direction, which reduces its strength. The rooms on the ground storey are being used for storage, rather than as offices. The building was apparently built in the 1980s and thus, is assumed not to have ductile detailing.

Figure 19. Maintenance office building

Bio-Medical Engineering Division (BMED) Office and Workshop

The Bio-Medical Engineering Division (BMED) is responsible for maintaining and repairing medical equipment. After an earthquake, they will need to inspect and repair the hospital's medical equipment. The building housing their offices and workshop, shown in Figure 20 (following page), is constructed of reinforced concrete frames with unreinforced masonry infill, and is approximately 30 years old. Several additions, probably using brick masonry, have been made to the original building to add storage and workshop space. The building has clerestorey windows with short columns above the central corridor. During the 2011 Sikkim earthquake, the unreinforced masonry panels moved within the reinforced concrete frame, opening up some minor cracks.

Figure 20. BMED office building and workshop

The building is vulnerable to significant damage in an earthquake, due to its age and lack of earthquake-resistant features. The unreinforced brick additions are especially vulnerable to damage. There is a possibility that BMED will move to a new building; the evaluation team recommends that move. The building additions contain storage for spare parts and supplies, as well as workshop space with some machinery and tools. BMED staff should ensure that storage shelves and racks are anchored to walls and that shelf contents are protected with shelf restraints, so that they do not fall and break. BMED will need to be able to access tools, supplies and machinery following an earthquake, or at minimum to retrieve them from the building, so that they can repair earthquake damaged medical equipment.

Staff Quarters

JDWNRH has a goal of providing forty percent of its staff with on-site residences. Accordingly, the hospital has numerous staff quarter buildings of different designs and ages. Limited information was available regarding the staff housing, but it appears to have been built in several major phases in the 1980s and 1990s. Table 9 shows the likely performance of various staff quarters in the three hypothetical scenario earthquakes considered in this report.

Table 9. Likely performance of staff quarters in hypothetical scenario earthquakes

Building Name	Construction Type	Year Built	No. of Stories (incl. ground)	Likely Performance in Hypothetical Scenario Earthquake		
				Moderate M6.1	Major M7	Severe M8.6
				PGA 0.25g	PGA 0.58g	PGA 1g
Staff Quarters						
MS Bungalow	Unreinforced brick*	1980s	1	S2	S3	S4
Doctors Bungalows	Unreinforced brick*	1980s	2	S2	S3	S4
Doctors Fourplexes	RC w/brick infill	1999	1	S1	S2	S3
Doctors Duplexes	Unreinforced stone masonry*	1980s	2	S1	S2	S3-S4
Nurses Type 1a 4-plex	RC w/block infill	1980s	2	S1	S2	S3
Nurses Type 1b 4-plex	Unreinforced stone masonry*	1980s	2	S2	S3	S4
Nurses Type 2 6-plex	RC w/brick infill*	1999	3	S1	S2	S3
Nurses Type 3 6-plex	RC w/brick infill	2001	3	S1	S2	S3
Nurses Type 4	Unreinforced brick*	1980s	2	S2	S3	S4
Ambulance drivers	URM*	1980s	2	S2	S3	S4

RC = reinforced concrete; URM = unreinforced masonry

* Exact construction material type and details are not known; assumed type is the most vulnerable of the likely construction material/structural system types. Vulnerability rating may improve if better, more earthquake-resistant construction can be verified.

Medical Superintendent's Quarters

The Medical Superintendent's residence, shown in Figure 21, appears to be built mostly of unreinforced masonry, most likely brick. The building has an irregular configuration in plan, and appears to have been added to over time. The kitchen at the back appears to have once been a separate building; ekra walls and a flat roof have been built to enclose the space between the kitchen and the main house. Toilet blocks are located on the side of the building.

Figure 21. Medical Superintendent's quarters with the main hospital in the background

Because the building has no diaphragm (a horizontal structural member that distributes earthquake forces to the building's frames and/or walls) and no obvious seismic bands, it is highly vulnerable to damage and is likely to collapse in a severe earthquake. The raised roof may lean, during strong earthquake shaking. The brick chimney in the kitchen at the back is likely to collapse even in a moderate earthquake. Given the importance of the MS to continued function of the hospital, the evaluation team strongly recommends that the quarters be seismically retrofitted or replaced as soon as possible.

The quarters also include a small detached residence for domestic staff, with a recently constructed brick masonry garage. This building appears to have been built at the same time as the main house and to be unreinforced masonry. It also has a highly vulnerable brick chimney. This building may suffer less damage than the main building, because it is small and has a regular configuration.

Doctors' Quarters – Bungalows

According to a site plan dated 2002, the hospital has eight single family residences, or bungalows, occupied by doctors and senior staff, in addition to the Medical Superintendent's residence. While little information is available for these buildings, they appear to have been constructed of unreinforced masonry, likely brick, sometime in the 1980s. Figure 22 shows two of these bungalows. The building on the left has very little wall across the front, making it relatively weaker. It also has a traditional raised roof, which may tilt or fall in an earthquake.

Figure 22. Two examples of single-family residences (bungalows) for doctors

Doctors' Quarters – Fourplexes

The hospital also has five doctors' fourplexes, shown in Figure 23 (following page), which are reinforced concrete buildings with brick masonry infill walls. These buildings were constructed in 1999. The evaluation team assumed that these buildings were designed to the Indian Standard in effect at the time, which means they would have incorporated some seismic design.

Figure 23. Doctors' fourplex residences

Doctors Quarters – Duplexes

The duplexes shown in Figure 24, which presumably house doctors or other senior staff, appear to be the same age as the nurses' quarters of similar design discussed below, and were likely built around the same time, the early 1980s. The buildings may be stone masonry with some reinforced concrete elements. There appear to be at least two dwelling units per building.

Figure 24. Multifamily doctors quarters

Nurses Quarters – Type 1a

Based on the team's observations, there are four of these buildings. The buildings were constructed in the 1980s. Two are painted and plastered, while two have exposed concrete block; Figure 25 (following page) shows an example of each type. There is a possibility that the painted and plastered buildings have a different wall material, but this is considered unlikely, since the buildings are otherwise identical. The buildings appear to have reinforced concrete frames, with columns at the building corners and perhaps in other locations. Due to their small size, regular configuration and the presence of columns, these buildings are significantly safer than other staff quarters of similar age.

Figure 25. Nurses quarters (Type 1a) with 4 units built of concrete block with some concrete columns; unplastered (left) and plastered (right)

Nurses Quarters –Type 1b

A second type of fourplex unit housing nurses and other staff members, also built in the 1980s, is shown in Figure 26. The evaluation team was told that these buildings were stone masonry, but the team was not able to verify this. As was the case for all the other buildings of this age, there were no drawings available. There are four of these buildings at the site.

Figure 26. Nurses' quarters (Type 1b) with four units

Nurses Quarters – Type 2

The older of two types of six-unit quarters are ground plus two storey reinforced concrete buildings with unreinforced masonry walls (presumably brick), shown in Figure 27 (following page). They appear to have been built in the 1990s. The buildings have a large vertical discontinuity in the middle, which makes them more vulnerable to earthquake damage. According to the 2002 site plan, there are six of these buildings at the site. No drawings are available, but the buildings were assumed to have been designed and built in compliance with IS 13920, the ductile detailing code for reinforced concrete buildings.

Figure 27. Nurses' quarters (Type 2) with 6 units and a large vertical discontinuity in the center of the building

Nurses Quarters –Type 3

The nurses' quarters shown in Figure 28 are ground plus two storey reinforced concrete with brick masonry infill walls. Architectural drawings are available for these buildings. There are two on the site, each with six units. The buildings were designed in 1998 by the Health Infrastructure Development Project, which has had a policy of following the Indian Standards for a number of years, and were built in 2001. The team assumed that these buildings were designed and built to the 1993 version of IS 13920, the reinforced concrete ductile detailing code.

Figure 28. Newer nurses quarters (Type 3) with 6 units

Nurses Quarters – Type 4

There is a single building of this type on the campus, shown in Figure 29 (following page). The evaluation team was not able to determine the number of units or to learn much about the building. It appears to be built of unreinforced masonry, and may have been built in the 1980s or 1990s.

Figure 29. View of nurses' quarter area showing Type 4 quarters on the far right

Ambulance Drivers' Quarters

The ambulance drivers' quarters are two eight-unit buildings, likely built in the 1980s. These buildings appear to be constructed of unreinforced masonry with reinforced concrete slabs, balconies and decorative elements. They have apparently non-functional chimneys that may separate from the main building and collapse in an earthquake. If these buildings are unreinforced masonry, then there is little solid wall area in the longitudinal direction, especially on the front side, making the buildings vulnerable to damage.

Figure 30. Front (left) and rear (right) views of ambulance drivers' quarters

Central Medical Store

The Central Medical Store, which stores the hospital's supplies, is located on the southeast side of the RIHS. The Central Medical Store is part of a complex belonging to the Drugs, Vaccines and Equipment Division (DVED) of the Ministry of Health. Access is from a separate road that runs behind Chamzangtok Middle Secondary School, less than one kilometer from the hospital. It is difficult to determine if the building housing the Central Medical Store is a reinforced concrete frame building with masonry infill walls, or an unreinforced masonry building. The team observed reinforced concrete beams, but did not observe any reinforced concrete columns. The building has a single tall storey to facilitate the storage of large volumes of supplies. The tall, relatively slender walls and large open interior spaces make the building much more vulnerable to earthquake damage.

Figure 31. Portion of the DVED building complex housing the Central Medical Store

The building appears to contain unbraced racks and shelves for storing medical supplies. The evaluation team did not have access to the interior of the building and could only view portions of the interior from outside. However, it is likely that supplies will fall to the floor or that racks will overturn in strong earthquake shaking, causing breakage and necessitating a major cleanup and restocking effort. Anchoring the racks to prevent toppling, and providing shelf restraints would prevent the loss of supplies and time-consuming restocking. Table 10 shows the likely performance of the Central Medical Store in the three hypothetical scenario earthquakes that the team considered.

Table 10. Likely performance of the Central Medical Store in hypothetical scenario earthquakes

Building Name	**Construction Type**	**Year Built**	**No. of Stories (incl. ground)**	**Likely Performance in Hypothetical Scenario Earthquake** (Structure and shell: left columns; equipment, pipes contents: right columns)					
				Moderate M6.1		Major M7		Severe M8.6	
				PGA 0.25g		PGA 0.58g		PGA 1g	
				Struct	Equip	Struct	Equip	Struct	Equip
Central Medical Store	URM or RC*	1997	1	S2	N2	S3	N3	S3	N3

* Exact construction material type and details are not known; assumed type is the most vulnerable of the likely construction material/structural system types. Vulnerability rating may improve if better, more earthquake-resistant construction can be verified.

Patients' Guest House

The Patients' Guest House is a ground plus one storey reinforced concrete frame building with assumed unreinforced masonry infill walls of an undetermined type. The guesthouse was established in 2008 with support from Her Royal Highness Ashi Kesang Wangmo Wangchuk, though the team understands that the building was originally built in 1992. The Guest House provides free lodging for economically disadvantaged patients who are receiving ongoing care at the hospital, as well as their families. As shown in Figure 32, the building has partial height masonry infill walls that create captive columns on parallel sides of the building, a significant earthquake vulnerability. There is an irregularly shaped toilet block (possibly an addition) at the rear of the building.

Figure 32. Patients' Guest House

Table 11 shows the likely performance of the Guest House in the hypothetical scenario earthquakes.

Table 11. Likely performance of the Patients' Guest House in hypothetical scenario earthquakes

Building Name	Construction Type	Year Built	No. of Stories (incl. ground)	Likely Performance in Hypothetical Scenario Earthquake		
				Moderate M6.1	Major M7	Severe M8.6
				PGA 0.25g	PGA 0.58g	PGA 1g
Patient Guest House	RC w/URM infill	1992	2	S2	S3	S4

Utility System Vulnerability 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 and water are supplied by the local grid or city water system, but almost all hospitals have backup supply capabilities in the event that utility service is interrupted, and JDWNRH is no exception. Other utilities, such as medical gas, must be supplied at the hospital. The hospital has on-site supply systems with major infrastructure and equipment, as well as distribution systems that provide services throughout the hospital building. Both on-site supply systems and distribution systems can be vulnerable to earthquake damage, which can interrupt utility services and impede or prevent the hospital from delivering essential medical services.

Damage to utility system components in numerous past earthquakes, along with recognition of the essential role that utility services play in functionality, has led earthquake engineering researchers to develop standard estimates, called *fragility functions*, of the levels of ground shaking at which unanchored equipment and utility system components will begin to experience damage or stop working.

The assessment team used engineering judgment and fragility functions from the Performance Assessment Calculation Tool (PACT) software, developed as part of the Applied Technology Council's Report ATC-58-1 *Guidelines for Seismic Performance Assessment of Buildings*, to estimate the potential availability of on-site utilities after the three hypothetical scenario earthquakes. The following sections present utility system vulnerabilities observed by the evaluation team, as well as estimates of performance in the three hypothetical scenario earthquakes.

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, lighting and other safety-critical items will not function. Following a moderate earthquake, it is highly likely that the supply from the electrical grid will be disrupted; grid power will certainly be lost for a significant period of time following a major or severe earthquake. Estimates of the time required to restore grid power following the hypothetical scenario earthquakes were outside the scope of this investigation, but Bhutan Power Corporation should be asked to provide such estimates for planning purposes. The transformers that receive the grid power supply are bolted to the skids, but the entire system that connects to the grid should be checked for seismic vulnerabilities to ensure that the hospital can access grid power, once it is restored.

During the critical response period immediately following the earthquake, and perhaps for weeks afterward, the hospital will need to rely on backup power supplied by the emergency generators. However, the generators and backup power system are vulnerable to earthquake damage that could prevent them from supplying the hospital with power when it is needed most. The team observed multiple vulnerabilities in the backup electrical power system. The emergency generators are not anchored and will likely slide off of their small vibration isolators (Figure 33) in strong earthquake shaking. The batteries that enable the generator to start are not anchored and may break or become disconnected.

Figure 33. Unanchored emergency generator with inadequately braced exhaust system and unsecured batteries (left); non-seismic vibration isolators (right)

Each generator has a tank that holds 990L, which will supply fuel for at most 16.5 hours of operation under normal conditions. Typically, two generators are used to power the hospital, with the third as backup. Under normal backup conditions (with two generators operating), the fuel supply would last a little more than 24 hours, assuming that all fuel on site can be transferred to two tanks (the tanks are not connected) and that two generators are operational. If power can be supplied to only the most essential functions after an earthquake (i.e., operation theatres, emergency department, etc.) using a single generator, then the supply of fuel could last longer, perhaps 50 hours in a best-case scenario. The Pan American Health Organization (PAHO) recommends that hospitals have a fuel supply sufficient to last five days (120 hours). Given Bhutan's geographic isolation, the hospital should keep fuel on hand for a much longer period of time than PAHO recommends, basing the amount of stored fuel on realistic estimates provided by Bhutan Power Corporation of the potential length of time required to restore grid power after a major earthquake.

The hospital's generators have never operated for more than three hours at a time. The generators are cooled with coolant, which must be added manually. Extra coolant is not stored on site, but this may not be necessary, unless overheating after long periods of use is a problem. However, if essential services can be run on one generator, it should be possible to use the generators on a rotating basis to prevent overheating, provided that the generators have all been anchored to prevent earthquake damage and are functional. This rotation approach must be tested in advance, to verify that it will work.

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. Pipes for wastewater protrude through the ceiling above the electrical cabinets and equipment, with inadequately constructed sheet metal pans hanging below to catch leaks. A major pipe leak or burst could damage the electrical equipment below and create a dangerous condition.

Table 12 shows the likely performance of the onsite electrical power system in the hypothetical scenario earthquakes considered in this report, as well as rough estimates of the availability of off-site grid power. The vulnerabilities in the electrical power system pose the greatest threat to the hospital's functionality, even in moderate and distant earthquakes.

Table 12. Likely performance of on-site electrical system in hypothetical scenario earthquakes

System	**Likely Performance in Hypothetical Scenario Earthquake**		
	Moderate M6.1 PGA = 0.25g	Major M7 PGA = 0.58g	Severe M8.6 PGA = 1g
Electric Power from off-site supply	May be short interruption of power	Interruptions of power are likely to be longer than 24 hours	Long interruptions of power should be expected
Electric Power from on-site generators	One or more of three emergency generators should be available. Emergency fuel supply should be adequate.	Generators and associated equipment may be damaged but one generator may be operational so power should be available. Length of time is limited to use of only one of the three fuel tanks. Fuel could be siphoned or pumped from	It is likely that none of the generators will be operational and the electrical equipment may also be damaged. Expect that power will not be available until emergency generators from off site are delivered and damaged equipment is repaired in an estimated 2-3

		other tanks to provide 50 hours of power. Additional fuel may not be available.	weeks or more.

Medical Gas System

The medical gas system relies on unanchored cylinders connected to manifolds (by flexible tubing) in the Service Block, shown in Figure 34, to provide a supply of oxygen and nitrous oxide, which is then piped into the main hospital building via the service bridge. During an earthquake, these cylinders will topple, disconnect from the manifolds, and possibly leak. Leaking oxygen creates a fire and explosion hazard.

Figure 34. Unsecured medical gas cylinders; note the space heater

The hospital likely has an insufficient emergency supply of medical gas, taking into account that gas must be brought from Phuentsholing and that the road will likely be closed by landslides for some time following a major earthquake. PAHO recommends that hospitals maintain a 15-day supply; JDWNRH generally keeps a 10-day supply, based on the usage rate under normal operating conditions. Following an earthquake, the usage rate could be higher due to the larger number of badly injured patients.

The hospital has central suction equipment in the room adjacent to the cylinder room, as well as two tanks outside. The compressors are bolted to their concrete pads, but the tanks are not bolted down and could topple in an earthquake. The medical gas distribution system is also vulnerable to breaks where the lines cross seismic joints in the main building and at both ends of the service bridge, unless flexible connectors have been provided.

Table 13 (following page) shows the likely performance of the medical gas systems in the three hypothetical scenario earthquakes.

Table 13. Likely performance of medical gas systems in hypothetical scenario earthquakes

System	Likely Performance in Hypothetical Scenario Earthquake		
	Moderate M6.1 PGA = 0.25g	Major M7 PGA = 0.58g	Severe M8.6 PGA = 1g
Medical Gas			
Oxygen and Nitrogen	Rack for cylinders is available but cylinders not anchored. Cylinders will fall over and rupture at least some of the piping. Could be down for 1 day until staff can straighten it up and reconnected.	Cylinder room will be in a considerable state of disruption. It could take several days to repair. Resupply from off campus may not be available.	Not available. Resupply not available.
Suction	Available	Probably available. Compressors are robust. Need power and distribution system, including tanks to be functional	Probably not available. Compressors and or distribution system will not be functional. Tanks are not bolted down and likely to topple.

Fire Suppression, Domestic and Drinking Water Systems

Under normal operating conditions, the hospital receives water from the city supply, which will most likely be unavailable for some time after a major earthquake. The hospital will need to function using stored water. The hospital's water storage tank has a capacity of 800,000L, of which 200,000L is for fire suppression and 800,000L is for domestic use. PAHO recommends that hospitals have domestic water storage capacity of 300L per bed per day, for at least three days (72 hours). Given Thimphu's geographic isolation, the hospital should have water storage for an additional period of time that should be determined based on the estimated time required to restore city water service. For 350 beds, the hospital should have 105,000L per day of domestic water per the PAHO recommendation. The domestic water tank stores 800,000L of water, so the tank has a supply adequate for approximately 7.5 days at normal usage levels. Following an earthquake, water could be rationed to extend the supply.

Assessment of the seismic vulnerability of the city water system is beyond the scope of this report, but damage requiring significant repair time has affected a number of water systems in past earthquakes elsewhere. The hospital should obtain an estimate of the likely time needed to restore city water service to determine whether the existing domestic water supply provided by the tank is likely to last until the city water is restored. If the tank's supply is insufficient, then the hospital should consider the costs and benefits of bolstering the supply, along with options such as rationing plans and providing emergency water from other sources. The fire suppression water supply may be adequate for one fire event.

Drinking water is provided by filtering domestic water using filter units dispersed in the wards and other areas of the hospital. The supply of drinking water therefore depends on the supply of domestic water, the availability of electricity, and prevention of earthquake damage to the filter units. Table 14 (following page) shows the likely performance of the hospital's water systems in the three hypothetical scenario earthquakes.

Table 14. Likely performance of water systems in hypothetical scenario earthquakes

System	**Likely Performance in Hypothetical Scenario Earthquake**		
	Moderate M6.1 PGA = 0.25g	Major M7 PGA = 0.58g	Severe M8.6 PGA = 1g
Water from off-site system	Water supply may be disrupted, but could be repaired prior to exhaustion of on-site tank.	Water supply probably disrupted and could take days to reestablish.	Water supply damaged and not repaired for extensive length of time.
Water from on-site storage			
Fire suppression	Supply from tank and distribution system adequate.	Supply from tank and distribution system adequate for one fire incident. Tank could then be exhausted.	Supply from tank and distribution system adequate for one fire incident. Tank could then be exhausted. Fire sprinkler piping likely to be damaged.
Domestic	Supply from tank and distribution system adequate.	Seven days of supply from tank may not be sufficient for length of time to repair off site system. Water rationing may be necessary.	Seven days of supply from tank will not be sufficient for length of time to repair off site system. Severe water rationing may be necessary, and emergency water will be needed to be provided from somewhere (tanker trucks, etc.)
Filtered Drinking	Likely to be adequate; depends on availability of power and proper anchorage of filter units to prevent earthquake damage.	Supply limit as per domestic water. Power may not be available if off site power is not restored before generator fuel exhausted.	Filters will not be functional due to loss of power so water will need to be boiled or treated; drinking water will be limited by domestic supply; emergency water will need to be provided.

Evaluation of the seismic resistance of the reinforced concrete water tank (shown in Figure **35**, following page) was outside the scope of this assessment, but it is possible that the tank, unreinforced masonry pump house, or pipes connecting the tank to the hospital could be damaged in an earthquake and cause leaks. Both the domestic and fire sprinkler piping systems are vulnerable to breaks and leaks in a major earthquake. The fire sprinkler drops are particularly vulnerable to damage, if the brick partitions fail and allow the suspended ceiling to swing back and forth. Leaks can lead to flooding of areas of the hospital, which can be very disruptive and lead to evacuation. The maintenance department should have procedures in place to quickly shut off water to affected areas in the event of leaks, both to reduce flooding and water damage, and to conserve the water supply. The table above assumes that leaks do not substantially reduce the supply of available water; note that major leaks could cause water loss and reduce the performance of the water system.

Figure 35. Drinking and fire suppression water storage tank (left); unreinforced masonry pump house below tank (right)

Communication Systems

The hospital currently uses both landline and mobile phones as its major communication systems. The mobile phone system was down for several hours immediately following the 2011 Sikkim earthquake[2], when shaking was light in Thimphu. The hospital should expect that mobile communications will be down for a longer period of time, perhaps a much longer period, following a larger earthquake like the M7 and M8.6 earthquakes considered in this report's scenarios. Mobile phone service providers have systems that rely on towers, electrical equipment and buildings that could be damaged in an earthquake and require repairs. Furthermore, individual mobile phones require electrical power to recharge, and service providers must have electricity to operate their systems.

The hospital will not be able to rely on mobile phones and does not have other backup communications. The 112 system is outside the scope of this report, but the team's observations regarding the call center located on the JDWNRH grounds are presented here. Table 15 shows the team's approximate estimates of disruption to communication systems in the three hypothetical scenario earthquakes. The hospital should obtain estimates from the telecommunications providers for planning purposes.

Table 15. Assumed performance of communication systems in hypothetical scenario earthquakes

System	**Assumed Performance in Hypothetical Scenario Earthquake**		
	Moderate M6.1 PGA = 0.25g	Major M7 PGA = 0.58g	Severe M8.6 PGA = 1g
Communications			
Landline phones/ switchboard	Probably operational	Service probably interrupted	Not operational for days to weeks, depending on damage and repair time
Mobile phones	Network unavailable for several hours	Network unavailable for hours to days	Network unavailable for days to weeks, depending on damage to towers and infrastructure and repair time

[2] *September 18, 2011 Earthquake: Joint rapid assessment for recovery, reconstruction and risk reduction*. Royal Government of Bhutan (RGoB), United Nations Bhutan, and the World Bank, 2011.

112 System Call Center	May be operational with emergency power from hospital generators;	Operation limited to length of time power is available from hospital and whether internet connectivity is available; system offline initially until equipment can be reconnected and building shored if needed; usage limited by disruptions to phone systems and internet.	Building may collapse, destroying equipment

Wastewater System

The hospital depends on the city sewer system for wastewater disposal. An assessment of the potential for the city system to be unavailable following strong earthquake shaking was outside the scope of this report, but this information should be obtained. Within the hospital site, the team observed several areas where wastewater piping could potentially suffer earthquake damage. The first area is in the ceiling of the Service Block's ground storey, shown in Figure 36, where sizeable wastewater pipes serving the kitchen are suspended without seismic bracing. In addition, these pipes are directly above electrical equipment; this is a code violation in many places. The light gauge metal trays provide inadequate protection from leaks. The second major area of concern is any location where wastewater piping crosses seismic joints between blocks in the main building. Differential movement between the blocks could break any pipes crossing the joint.

Figure 36. Suspended, unbraced wastewater pipes above a generator and electrical equipment in the Service Block

Heating, Ventilation and Air Conditioning Systems

The hospital has three unanchored boilers, located in the Service Block, which provide steam for heat, plus an unanchored hot water generator. Figure 37 (following page) shows unanchored boilers, hot water generator and large pipes without flexible connectors, suspended from the ceiling without lateral bracing; the frame hangers do not provide adequate lateral support. The Service Block's tall, relatively flexible first storey will mean that the ceiling slab may move enough relative to the floor to damage pipes. Inside the main hospital building, any hot water pipes that cross seismic joints need to have flexible connectors at the crossings to avoid breakage caused by differential movement of the blocks. The team did not view the air handling units in the main hospital, but these may be vulnerable as well.

Figure 37. Unanchored boilers (left) and laterally unbraced pipes (right) in the Service Block

Lifts

The evaluation team assumed that the lifts were not designed for earthquake forces, because there are no seismic provisions for lifts in the Indian Standards. 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. In addition, lift machinery and controls were presumed to be unanchored. It should be noted that lift machinery is located at the top of buildings, where shaking tends to be strongest, because the building amplifies earthquake motions.

Vulnerability of Medical Equipment, Contents, and Architectural Shell

A hospital's medical equipment, contents such as medicines and supplies, and the building's architectural shell are all important for maintaining essential services and protecting patients. At JDWNRH, many of these items were apparently not designed or installed with earthquake safety or protection in mind: the team observed widespread earthquake vulnerabilities. A systematic survey of medical equipment and contents was outside the scope of this assessment, but the team recommends that the hospital conduct such a survey. The following sections describe the evaluation team's findings.

Medical Equipment

JDWNRH contains the majority of Bhutan's costly, specialized medical equipment, representing years of investment that needs seismic protection. Figure 38 (following page) illustrates this need: a line of specialized mobile equipment used in the operation theatres is stored, untethered, in a hallway behind the OTs; one of only eight dialysis machines in western Bhutan (though regional referral hospitals in Mongar and Gelephu have a limited number of dialysis machines available) remains unsecured.

Figure 38. Mobile equipment used in OTs stored without tethers in hallway (left); tall, narrow dialysis equipment (right)

Some of this equipment, such as the sterilizers shown in Figure 39 below, is critical to the hospital's ability to deliver emergency medical care. Most of the hospital's medical equipment - with the exception of equipment that must be well-anchored for ordinary service, such as operation theater lights and CT scanners - is not anchored or otherwise appropriately protected (i.e., sensitive mobile equipment should be tethered when not in use). Some equipment, such as the X-ray equipment shown in Figure 40 (following page), has not been installed in an earthquake-resistant manner. The Bio-Medical Engineering Division maintains an inventory of medical equipment worth more than $2000, which would serve as an excellent starting point for a ranked list of critical medical equipment requiring seismic protection.

Figure 39. Inspecting unanchored sterilizers in the Central Sterilization and Supply Department (CSSD)

Figure 40. X-ray equipment supported by beam resting on seismically unstable brick partitions

Contents and Furnishings

In several areas of the main hospital building, the Service Block and the Central Medical Store, important items such as medicines, sterile surgical instruments and medical records are stored on unanchored shelving that may topple in an earthquake, such as that shown in Figure 41 below.

Figure 41. Unanchored racks with unrestrained medicines in inpatient pharmacy, top level of Service Block

Figure 42 (following page) shows two areas with desks and work stations located near heavy shelves that could topple and injure staff members during an earthquake. In the Central Medical Store, items are also in tall, narrow stacks resting on the floor, as Figure 43 (following page) shows. In all of these locations, unrestrained items will fall, become disorganized or ruined, and require time-consuming cleanup or restocking. Simple hardware to anchor shelving to walls or floor, combined with shelf restraint systems, can prevent this from happening.

Figure 42. Large, unanchored medical records shelving (left) and unsecured racks in CSSD (right) near staff workstations

Figure 43. Supplies stacked in Central Medical Store

Architectural Shell: Elements and Finishes

The architectural shell consists of the building's partitions, suspended ceilings, windows, roof covering and exterior architectural elements. The architectural shell defines functional spaces and facilitates infection control and fire protection. The brick partitions and suspended ceilings, key parts of this shell, are vulnerable to damage during strong earthquake shaking.

Brick Partitions

The hospital has single wythe (i.e., built from a single row of bricks) brick partitions that extend from floor slab to floor slab. The partitions are very slender, given the hospital's tall floor-to-floor heights. As a result, they would tend to buckle and collapse in an earthquake, especially those partitions in upper floors, where the building's motion is amplified. Because such partitions can fail, medical equipment should not be anchored to them. Instead, the evaluation team recommends that equipment be anchored to floor-to-ceiling supports called *strongbacks*.

Suspended Ceilings

The main hospital building has suspended ceilings, constructed of panels that are screwed to a light metal frame hung from the floor slab above. The ceilings span from partition to partition. Figure 44 shows a typical suspended ceiling support system, which has no lateral bracing, and which also has unbraced utility service pipes for domestic water, fire suppression water, medical gas and steam. While these ceilings are more robust than lay-in acoustical tile ceilings prevalent in other areas, they are still prone to damage, if the partitions that provide lateral bracing collapse.

Figure 44. View above suspended ceiling showing support system and utility services. There is no lateral bracing for the suspended ceiling, fire and domestic water pipes, medical gas lines and steam pipes.

The hospital's medical buildings also have window glass and decorative elements on the exterior that could potentially be damaged and fall on people nearby in an earthquake. The Old Building has an entrance canopy on the south side that may be vulnerable to collapse in strong shaking.

Dependence on Off-site Lifelines

Thimphu does not have facilities that manufacture the supplies, fuel and medical gas that the hospital needs to provide medical care. The hospital depends on transportation lifelines for resupply of these items. Most resupply items come from Phuentsholing over a narrow, winding mountain road prone to landslides and rockfalls. Moderate to severe earthquakes such as the three hypothetical scenarios considered here will cause landslides to occur on the roads that connect Thimphu to the international airport at Paro and to other parts of the country, including Phuentsholing. Following a major earthquake, it may take days or weeks to reopen the road between Thimphu and Phuentsholing. The runway of the international airport at Paro may be damaged in more severe shaking. Humanitarian relief efforts will be impeded, as a result. It will be difficult to refer patients to hospitals outside the country.

Mobile telephone service will become jammed with calls following a damaging earthquake; in a more severe earthquake, cell towers and infrastructure may be damaged, and the electrical power needed by users and mobile phone infrastructure will not be available.

City water and grid-supplied electrical power systems are likely to be damaged by strong earthquake shaking, and may be unavailable for days or weeks. The city sewer system and solid waste disposal may suffer significant interruptions in regular service following a strong earthquake. The team did not assess vulnerabilities of these systems, but based these general remarks on past performance of other utility systems in earthquakes. For planning purposes, the hospital should obtain estimates of the time required for each of these utilities to restore service.

Emergency Planning

The evaluation team interviewed the Medical Superintendent to obtain the information contained in this section. The hospital has some emergency procedures in place, and administration and staff are interested in earthquake preparedness, but there is no formal emergency plan addressing earthquakes.

Though the hospital does not currently have a formal emergency plan written, procedures are in place for dealing with mass casualties resulting from an external disaster; these procedures include elements of an incident command system. The procedures were tested by a truck accident earlier in 2012, and the Medical Superintendent found them to be adequate. However, the Medical Superintendent noted that because there was no plan to implement in the event of an earthquake, and he was not present, the staff did not know what to during and after the 2011 Sikkim earthquake; people did what they thought was best. The staff felt the earthquake shaking but fortunately, no damage was reported, except for a few insignificant cracks in finishes. A previous Medical Superintendent worked on an emergency plan, but a new plan is needed that is compatible with the recently developed Health Sector Disaster Management and Contingency Plan. The Medical Superintendent would like to develop a plan and requested information and technical assistance from GHI.

The hospital does not have a formal disaster committee. Past efforts to improve the hospital’s ability to respond have been initiated by a small number of concerned staff members.

The hospital does not keep a stockpile of supplies dedicated for use in a mass casualty event or disaster, but it does store up to a year’s worth of supplies in the Central Medical Store. GHI recommends that the hospital’s emergency plan specifically address how to retrieve supplies from the central supply, in the event that access to the central supply is disrupted by damage to the central supply building, or because the routes between the hospital and central supply building are damaged or blocked by debris.

The hospital has a well-established system for transferring patients out of the country, which will be useful following a major damaging earthquake, assuming that emergency air transportation can be made available.

Health Help Center

The call center for Bhutan's national medical emergency hotline (112), the Health Help Center, is located on the JDWNRH campus. Evaluation team members visited the Center and interviewed its Chief Executive Officer. The call center is housed in a brick masonry building, originally built as a hostel for the RIHS in the 1970s. The call center relies on the hospital's emergency generators for backup power. As discussed in previous sections, these generators are not anchored and are likely to suffer earthquake damage that may prevent them from functioning after a strong earthquake. GHI recommends that the Health Help Center take the following actions:

- Brace server cabinets to prevent toppling and damage in an earthquake;
- Obtain an independent source of backup power, and protect that source from earthquake damage by properly anchoring equipment;
- Seek to move to a building less likely to suffer heavy damage in a major earthquake;
- Consider co-locating with an Emergency Operations Center (EOC), if and when one is built.

Hospital Impact Scenarios Based on Three Hypothetical Earthquakes

To help readers envision the impact of potential earthquake damage on the hospital's ability to function and deliver care, the evaluation team has postulated how the facility might respond to three scenario earthquakes. Each scenario is based on a hypothetical earthquake and is intended to illustrate the range of earthquake shaking that the hospital should consider for mitigation and emergency planning purposes. The three hypothetical earthquakes are (1) a moderate M6.1 earthquake occurring near Thimphu; (2) a major M7 earthquake occurring near Thimphu; and (3) a massive M8.6 earthquake occurring on the plate boundary and affecting much of Bhutan. The USGS, with collaboration from University of Indiana and DGM, provided preliminary estimates of the median levels of ground shaking that these three earthquakes might cause.

The USGS estimates of potential shaking presented in this report contain large uncertainties, because the scientific community's understanding of Bhutan's earthquake hazard is still at an early stage. A real earthquake, even if it were to have the same magnitude and to originate in exactly the same location, might cause shaking that is substantially stronger or substantially weaker than the estimates presented in this report. The report presents these estimates for purposes of illustration only. They should not be used for engineering design, both because of the uncertainties involved and because they consider only approximate, generalized site conditions; local site effects could further affect the amplitude and nature of ground shaking. These estimates may be used for emergency planning, with appropriate precautions that account for the uncertainties involved.

While these earthquakes are hypothetical, they represent the types of earthquakes that Bhutan should anticipate. Moreover, they are of reasonable magnitudes and plausible locations, and are not the worst case scenarios.

The following sections describe each scenario, providing an overview of possible infrastructure and building damage in the earthquake-affected area and a description of the earthquake damage and consequences that the evaluation team considers likely to occur at the hospital, as a result of the vulnerabilities identified in prior sections. The scenarios have intentionally been kept simple and are intended to give the reader a snapshot of the hospital's performance following each hypothetical earthquake. Much more detailed scenarios, with a timeline extending a month for larger earthquakes due to the complexity of interactions with the transportation and utility systems, would be used for emergency planning purposes. In the final section of this report, the team provides recommendations for actions that will reduce the earthquake damage to the hospital and lessen its consequences.

Postulated levels of earthquake damage determined for the estimated shaking were assigned using the damage states defined in Table 1. The team estimated the likely functionality of each building by combining the damage states with a determination of whether or not critical utilities (electrical power and domestic water) would be available. Table 16 defines the likely functional states by color codes used to present a graphical overview for each scenario.

Table 16. Functional state color codes

Color Code	Description of Functional State	Damage states	Critical Utilities
Black	Collapsed or partially collapsed	S4	N/A
Red	Neither useable nor functional	S3 plus N3 (if applicable)	Not available
Orange	Marginally useable but not functional For residences: damaged; may not be habitable	S1 / S2 plus N3 Or S2 plus N2	Not available
Yellow	Functional after cleanup / minor repair For residences: damaged: habitable with cleanup	S2 plus N1 (if applicable) or S1/S2 plus N2	Available
Green	Functional For residences: habitable	S1 plus N1 (if applicable)	Available

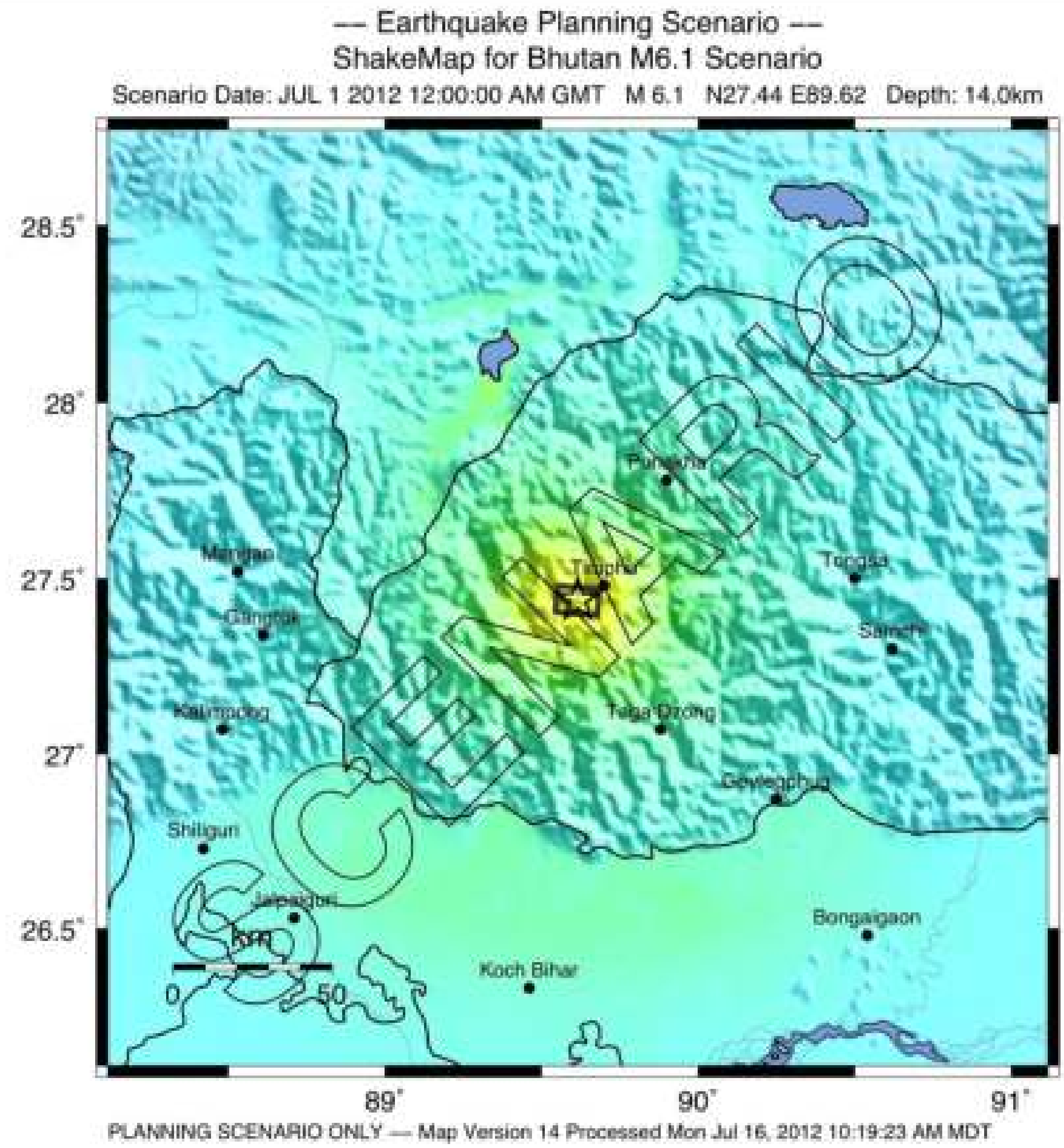
Scenario 1: Hypothetical M6.1 Earthquake Occurring Near Thimphu

At 7:00 a.m. on a chilly Wednesday in November, a magnitude 6.1 (M6.1) earthquake occurs on the main fault some 14 kilometers beneath Thimphu. Figure 45 (following page) shows a potential pattern of ground shaking in the M6.1 earthquake, estimated by the USGS using their ShakeMap system. Thimphu is indicated by a black dot. The box indicates the portion of the fault that ruptured to generate the earthquake. The shaking is strong to very strong in Thimphu, moderate to strong in Paro, moderate in Punakha, Wangdue Phodrang, and Haa, and light throughout western and central Bhutan.

Throughout Thimphu, buildings have been damaged: brick infill walls in apartment buildings and offices, especially on the upper floors, have fallen inside the buildings and out into the streets. Because the earthquake occurred at an early hour, the sidewalks were relatively empty. Some people inside of buildings were injured by falling bricks and furniture, or scalded by pots of boiling water kept on stoves.

Some rammed earth buildings have collapsed, killing or injuring some occupants; others have been badly damaged and are not safe to occupy.

Numerous small landslides and rockfalls as far south as Chhukha have blocked the road between Thimphu and Phuentsholing. There is a large rockslide blocking the road to Paro just north of Chhudzom, and numerous smaller rockfalls. Some streets in Thimphu are partially blocked by fallen bricks and other debris, but the main roads are drivable. One bridge between Thimphu and Paro has been damaged.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	<0.02	0.1	1.4	4.7	9.6	20	41	86	>178
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2011)

Figure 45. Median estimate of potential ground shaking intensity from M6.1 hypothetical scenario earthquake near Thimphu, courtesy USGS. The black box indicates the portion of the fault that ruptured during the earthquake.

Inside JDWNRH, staff and patients feel the earthquake shaking and are unsure of what to do. Unrestrained supplies fall from carts and shelves. The power fails, but the emergency generators come on almost immediately and restore power. The Medical Superintendent and staff living on site who are not already at work rush to the hospital, after checking that their families are all right. They notice that the walls of some of their quarters have cracked and hope that the HIDD engineers arrive soon to check the buildings. The mobile phone network is overloaded within minutes of the earthquake. The hospital staff is unable to contact the doctors who live offsite and have no idea when or if they will arrive.

HIDD engineers arrive and inspect all buildings on the site. The hospital building, service block and filter clinic have some very minor cracks in the plaster, but no structural damage. The old building (painted gray, next to the filter clinic), its back wings, and the patients' guest house have structural damage. The community health buildings have some cracks in the masonry walls, as do the HIDD, BMED and maintenance offices and the Central Medical Store. The MS's quarters, doctors' bungalows, ambulance drivers' quarters and the nurses' fourplexes on the north side of the hospital, which are all built of unreinforced brick or stone masonry, have some cracks in walls. Table 17 shows the damage states (defined in Table 1) that the team anticipates the M6.1 hypothetical scenario earthquake to cause.

Table 17. Likely damage states for hospital buildings after M6.1 hypothetical scenario earthquake

Building Name	**Construction Type**	**Year Built**	**No. of Stories (incl. ground)**	**Likely Performance in M6.1 Hypothetical Scenario Earthquake**, PGA 0.25g	
				Structure & Shell	Equip & Contents
New Main Hospital					
Block A	RC w/brick infill	2008	5	S1	N1
Block B	RC w/brick infill	2008	6	S1	N1
Block C	RC w/brick infill	2008	6	S1	N1
Block D - Ramp	RC w/brick infill	2008	6	S1	N1
Block E	RC w/brick infill	2008	5	S1	N1
Block F	RC w/brick infill	2008	3	S1	N1
Block G	RC w/brick infill	2008	6	S1	N1
Parking Garage	RC frame	2008	6	S1	N/A
Service Block/pharmacy	RC w/brick infill	2008	3	S1	N2
Bridge from Service Block to Main Bldg.	RC frame	2008	2	S1	N1**
Filter Clinic and Old Bldg.					
Filter Clinic	RC w/brick infill	1997	3	S1	N1
Old Building main	Nonductile RC w/brick infill	1972 or later	2	S2	N1
Old Building rear addn	Mixed*	1980s	2	S2	N2
Community Heath					
Old Pediatric Ward	Nonductile RC w/infill	1980s	2	S1-S2	N/A
Upper L-shape bldg.	URM*	2000s	1	S2	N/A
Hand Therapy Clinic	URM*	1980s	1	S2	N/A
TB and vol. testing 55ldg..	URM*	1980s	1	S2	N/A
Psychiatric Ward (front)	URM*	1980s	1	S2	N/A

Psychiatric Ward (rear)	Nonductile RC w/infill	1980s	2	S2	N/A
Health Help Center	Unreinforced brick	1970s	1	S2	N2
HIDD Office	URM*	1980s	1	S2	N/A
Maintenance Office	RC w/brick infill	1980s	2	S2	N/A
BMED Office	RC w/brick infill	1980s	1	S2	N/A
Staff Quarters					
MS Bungalow	Unreinforced brick*	1980s	1	S2	N/A
Doctors Bungalows	Unreinforced brick*	1980s	2	S2	N/A
Doctors Fourplexes	RC w/brick infill	1999	1	S1	N/A
Doctors Duplexes	Unreinforced stone masonry*	1980s	2	S1	N/A
Nurses Type 1a 4-plex	RC w/block infill	1980s	2	S1	N/A
Nurses Type 1b 4-plex	Unreinforced stone masonry*	1980s	2	S2	N/A
Nurses Type 2 6-plex	RC w/brick infill*	1999	3	S1	N/A
Nurses Type 3 6-plex	RC w/brick infill	2001	3	S1	N/A
Nurses Type 4	Unreinforced brick*	1980s	2	S2	N/A
Central Medical Store	URM*	1997	1	S2	N2
Patient Guest House	RC w/URM infill	1992	2	S2	N/A

RC = reinforced concrete; URM = unreinforced masonry
* Exact construction material type and details are not known; assumed type is the most vulnerable of the likely construction material/structural system types. Vulnerability rating may improve if better, more earthquake-resistant construction can be verified.
** Pipes and services at joints

In the Service Block, some unanchored medical gas cylinders topple and break their connections to the manifolds. The oxygen and nitrous oxide supply to the hospital is interrupted for at least several hours, and probably a day, as maintenance staff repair damaged connections and check the distribution system for leaks. Staff members bring some undamaged cylinders into the hospital building and manually connect them to medical equipment in the hospital's critical service areas. The generators are functional, but there is limited fuel on hand, and the road may not be open for 1-2 days. The hospital operates on one generator, and all non-essential lights and equipment are turned off to save power. Table 18 (following page) shows the anticipated performance of the most important utility systems in the M6.1 hypothetical scenario earthquake.

Table 18. Likely performance of key utility systems in M6.1 hypothetical scenario earthquake

System	Likely Performance in Hypothetical M6.1 Scenario Earthquake, PGA = 0.25g
Electric Power from off-site supply	May be short interruption of power
Electric Power from on-site generators	One or more of three emergency generators should be available. Emergency fuel supply should be adequate.
Water from off-site system	Water supply may be disrupted, but could be repaired prior to exhaustion of on-site tank.
Water from on-site storage	
Fire suppression	Supply from tank and distribution system adequate.
Domestic	Supply from tank and distribution system adequate
Filtered Drinking	Likely to be adequate; depends on availability of power and proper anchorage of filter units to prevent earthquake damage.
Communications	
Landline phones	Probably operational
Mobile phones	Network unavailable for several hours
112 System Call Center	May be operational with emergency power from hospital generators
Medical Gas	
Oxygen and Nitrogen	Rack for cylinders is available but cylinders not anchored. Cylinders will fall over and rupture at least some of the piping. Could be down for 1 day until staff can straighten it up and reconnected.
Suction	Available

Soon after the earthquake, injured people began to arrive at the hospital. Injuries are primarily lacerations and fractures caused by falling bricks and heavy furniture, and burns. After about an hour, a small number of seriously injured people begin to arrive at the hospital. Family members or neighbors rescued them from collapsed buildings. Many have suffered fractures and crush injuries. These cases trickle in over the next 36 hours, as the local police and military rescue more trapped people. The loss of medical gas supply affects some critical patients, but the hospital is able to maintain most essential functions and treat those injured by the earthquake.

Figure **46** (following page) shows the anticipated performance of the hospital's buildings, in terms of functionality. The actual state of functionality is highly uncertain, due to uncertainty in the exact nature of ground shaking and in the team's existing knowledge of structural and nonstructural systems. Each building could be one performance level higher or lower than shown. One performance level is shown for illustrative purposes. Short term interruptions of services that do not require evacuations are not considered.

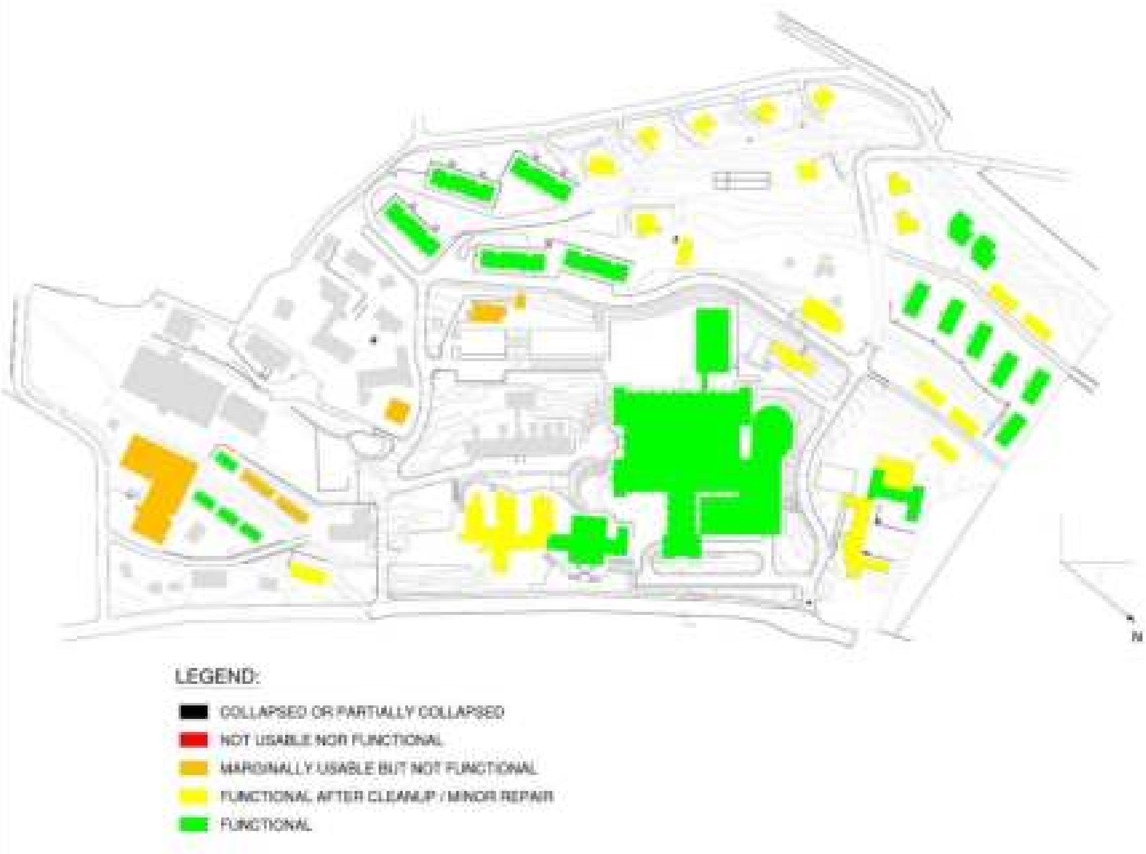
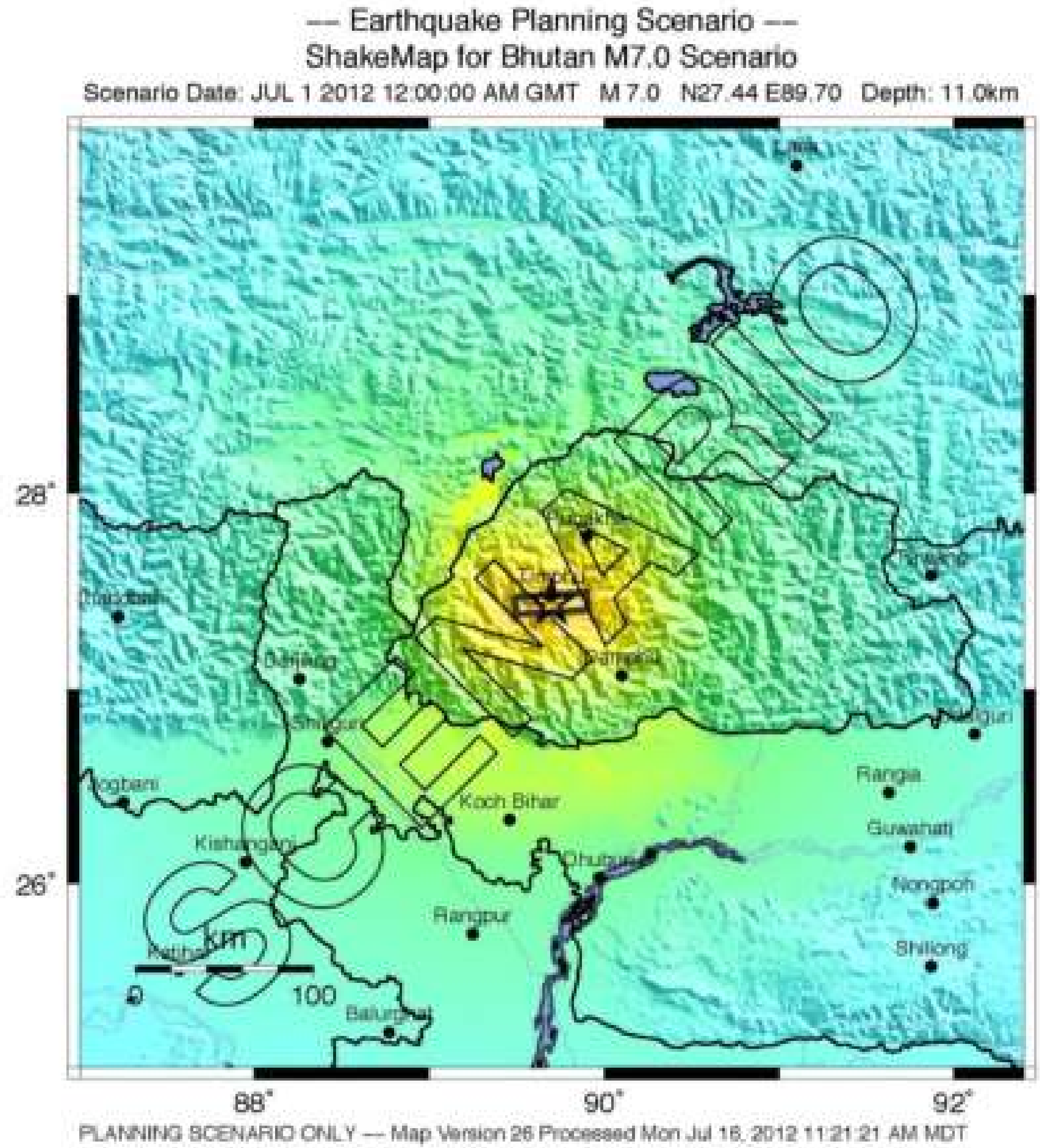


Figure 46**. Site plan showing performance of hospital buildings in M6.1 hypothetical scenario earthquake**

Scenario 2: Hypothetical M7 Earthquake Occurring Near Thimphu

Just before 11:00 a.m. on a Saturday morning, Thimphu is shaken by a magnitude 7 (M7) earthquake. The shaking is felt strongly throughout most of western Bhutan. Figure 47 (following page) shows a potential pattern of ground shaking intensity in this earthquake, as estimated by the USGS using their ShakeMap system. Thimphu is indicated by a black dot. The star indicates the earthquake's epicenter, and the box shows the portion of the fault that the USGS assumed had ruptured in order to generate this hypothetical earthquake.

There is widespread damage to buildings in both Thimphu and Paro, as well as in smaller communities in both districts. A small number of building collapses are reported in Punakha, Wangdue Phodrang, Chhukha and Haa. There is some damage in Phuentsholing and in the neighboring Indian city of Jaigon. In Thimphu city, many newer apartment buildings suffer damage, with bricks walls used to provide traditional-looking architectural features in the uppermost stories falling into the street. Many people have been injured by falling bricks and other falling objects, and are brought to the hospital by family members and neighbors. Others have fallen down stairs trying to run out of buildings and have broken bones. Over the next several days, people are rescued from collapsed buildings but have fractures and crush injuries. Some of those trapped in the rubble for lengthy periods of time are suffering from crush syndrome, and are weak from blood loss and dehydration.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.1	0.5	2.4	6.7	13	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	11	22	43	83	>160
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

Figure 47. Median estimate of potential ground shaking intensity from M7 hypothetical scenario earthquake near Thimphu, courtesy USGS. The black box indicates the portion of the fault that ruptured during the earthquake.

Initially, the injured arrive from only Thimphu city, because numerous small landslides close the road between Thimphu and Chhudzom. Landslides also close other roads in the region, and major slides have come down in several locations where geologic conditions make the area especially landslide-prone. From Chhudzom, major slides block both the road to Paro and the road to Phuentsholing. DANTAK (part of India's Border Roads Organization that builds and maintains roads in Bhutan) estimates that it will take at least a week to clear the major slides. In Thimphu, the old road has suffered some damage due to landslides and failure of the roadbed. Some narrower city streets are blocked or partially blocked by debris from collapsed buildings or fallen walls. Several bridges have been damaged.

Inside the main hospital building, the earthquake shaking is strong and causes cracks in some of the brick infill walls and many partitions. Some partitions fail in the upper storeys. In some locations, small cracks appear at the ends of reinforced concrete beams. Supplies fall from carts, shelves and racks. Medical records fall to the floor and are disorganized. In the Central Sterilization and Supply Department, racks overturn and spill sterile supplies onto the floor, and some sterilizers overturn and break the attached water pipes. A few areas in wards are uninhabitable, and patients must be moved. The ramp structure has suffered moderate damage, and the staff is unsure of its safety. The elevators are not working, and patients must be carried down stairs to move between floors. A ceiling-mounted X-ray machine with rails unanchored to the building frame is damaged and inoperable. With many patients presenting with fractures, the radiology department feels the loss of the X-ray acutely.

Many older buildings on the campus suffer heavy damage. Some are at risk of collapse in an aftershock. Table 19 shows the anticipated damage states (defined in Table 1) for the hospital's buildings for this M7 hypothetical scenario earthquake.

Table 19. Likely damage states for buildings in M7 hypothetical scenario earthquake

Building Name	**Construction Type**	**Year Built**	**No. of Stories (incl. ground)**	**Likely Performance in M7 Hypothetical Scenario Earthquake** PGA 0.58g	
				Structure & Shell	Equip & Contents
New Main Hospital					
Block A	RC w/brick infill	2008	5	S2	N2
Block B	RC w/brick infill	2008	6	S2	N2
Block C	RC w/brick infill	2008	6	S2	N2
Block D – Ramp	RC w/brick infill	2008	6	S3	N2
Block E	RC w/brick infill	2008	5	S2	N2
Block F	RC w/brick infill	2008	3	S2	N2
Block G	RC w/brick infill	2008	6	S2	N2
Parking Garage	RC frame	2008	6	S3	N/A
Service Block/pharmacy	RC w/brick infill	2008	3	S2	N2
Bridge from Service Block to Main Bldg.	RC frame	2008	2	S1	N2-N3**
Filter Clinic and Old Bldg.					
Filter Clinic	RC w/brick infill	1997	3	S2	N2
Old Building main	Nonductile RC w/brick infill	1972 or later	2	S3	N2
Old Building rear addn	Mixed*	1980s	2	S3	N2
Community Heath					
Old Pediatric Ward	Nonductile RC	1980s	2	S2	N/A

	w/infill				
Upper L-shape bldg.	URM*	2000s	1	S3	N/A
Hand Therapy Clinic	URM*	1980s	1	S3	N/A
TB and vol. testing 61ldg..	URM*	1980s	1	S3	N/A
Psychiatric Ward (front)	URM*	1980s	1	S3	N/A
Psychiatric Ward (rear)	Nonductile RC w/infill	1980s	2	S3	N/A
Health Help Center	Unreinforced brick	1970s	1	S3	N3
HIDD Office	URM*	1980s	1	S3	N/A
Maintenance Office	RC w/brick infill	1980s	2	S2	N/A
BMED Office	RC w/brick infill	1980s	1	S2	N/A
Staff Quarters					
MS Bungalow	Unreinforced brick*	1980s	1	S3	N/A
Doctors Bungalows	Unreinforced brick*	1980s	2	S3	N/A
Doctors Fourplexes	RC w/brick infill	1999	1	S2	N/A
Doctors Duplexes	Unreinforced stone masonry*	1980s	2	S2	N/A
Nurses Type 1a 4-plex	RC w/block infill	1980s	2	S2	N/A
Nurses Type 1b 4-plex	Unreinforced stone masonry*	1980s	2	S3	N/A
Nurses Type 2 6-plex	RC w/brick infill*	2000	3	S2	N/A
Nurses Type 3 6-plex	RC w/brick infill	2001	3	S2	N/A
Nurses Type 4	Unreinforced brick*	1980s	2	S3	N/A
Central Medical Store	URM*	1997	1	S3	N3
Patient Guest House	RC w/URM infill	1992	2	S3	N/A

RC = reinforced concrete; URM = unreinforced masonry
* Exact construction material type and details are not known; assumed type is the most vulnerable of the likely construction material/structural system types. Vulnerability rating may improve if better, more earthquake-resistant construction can be verified.
** Pipes and services at joints

In the Service Block, there is some damage to the backup power system. One generator has fallen from its supports, and the exhaust system on another generator is damaged. The hospital has one operational generator, so there is some power supply for essential services in the main hospital building; the other buildings are without power. The limited fuel supply is cause for concern, because it may take a week to open the road, and the supply on hand will only last 50 hours. Many unanchored medical gas cylinders topple and break their connections to the manifolds. Oxygen leaks create a fire hazard. The oxygen and nitrous oxide supply to the hospital is interrupted for several days, as the maintenance staff repairs damaged connections and broken lines in the distribution system. The maintenance staff is stretched very thin; some have been injured in the earthquake and are unable to work. Staff members are able to salvage some undamaged cylinders that can be brought into the hospital and manually connected to life support equipment. The supply of medical gas may not last until the road to Phuentsholing reopens. Along with medical gas lines, some fire sprinkler pipes have broken, producing area flooding. Table 20 shows the anticipated performance of key utility systems in the M7 hypothetical scenario earthquake.

Table 20. Likely performance of key utility systems in M7 hypothetical scenario earthquake

System	**Likely Performance in M7 Hypothetical Scenario Earthquake**, PGA = 0.58g
Electric Power from off-site supply	Interruptions of power are likely to be longer than 24 hours
Electric Power from on-site generators	Generators and associated equipment may be damaged but one generator may be operational so power should be available. Length of time is limited to use of only one of the three fuel tanks. Fuel could be siphoned or pumped from other tanks to provide 50 hours of power. Additional fuel may not be available.
Water from off-site system	Water supply probably disrupted and could take days to reestablish.
Water from on-site storage	
Fire suppression	Supply from tank and distribution system adequate for one fire incident. Tank could then be exhausted.
Domestic	Seven days of supply from tank may not be sufficient for length of time to repair off site system. Water rationing may be necessary.
Filtered Drinking	Supply limit as per domestic water. Power may not be available if off site power is not repaired before generator fuel exhausted.
Communications	
Landline phones	Service probably interrupted
Mobile phones	Network unavailable for hours to days
112 System Call Center	Operation limited to length of time power is available from hospital and whether internet connectivity is available; system offline initially until equipment can be reconnected and building shored (if needed); usage limited by disruptions to phone systems and internet.
Medical Gas	
Oxygen and Nitrogen	Cylinder room will be in a considerable state of disruption. It could take several days to repair. Resupply from off campus may not be available.
Suction	Probably available. Compressors are robust. Need power and distribution system, including tanks to be functional

Figure **48** (following page) shows the anticipated performance of the hospital's buildings, in terms of functionality. The actual state of functionality is highly uncertain, due to uncertainty in the exact nature of ground shaking and in the team's existing knowledge of structural and nonstructural systems. Each building could be one performance level higher or lower than shown. One performance level is shown for illustrative purposes. Short-term interruptions of services that do not require evacuations are not considered. Most areas of the main hospital building would be functional after some cleanup, but the lack of medical gas limits certain essential functions. Damage to the ramp block and lifts impedes the movement of patients between floors. Some staff quarters, the central medical store, the old and the community health buildings are all heavily damaged and may be unsafe to use. The hospital is able to deliver some essential care for a limited time period, until the generator fuel and water supply run out.

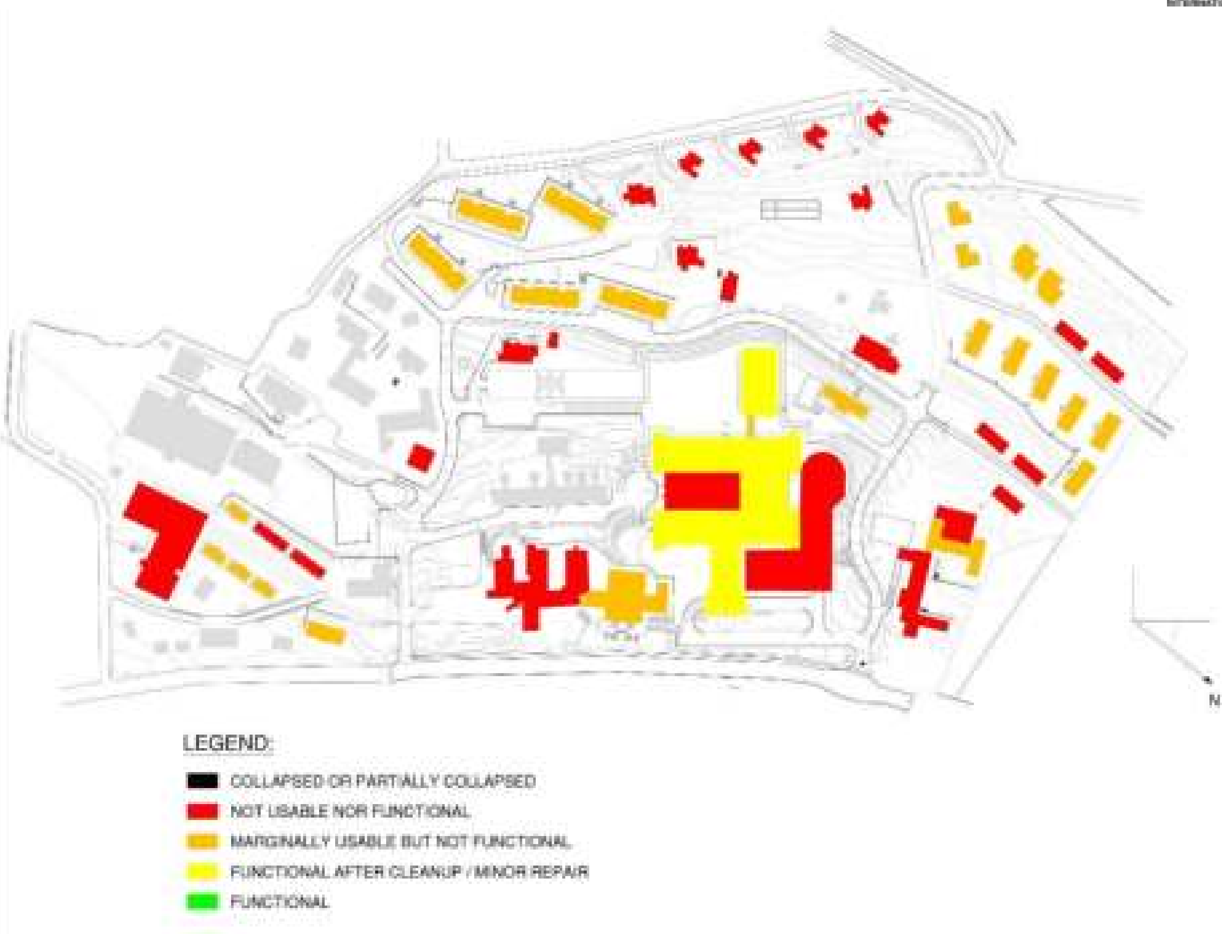


Figure 48. Likely performance of hospital buildings in M7 hypothetical scenario earthquake

Scenario 3: Hypothetical M8.6 Earthquake Affecting Most of Bhutan

The worst earthquake to affect Bhutan in approximately 900 years strikes in the middle of a working day. The massive M8.6 earthquake ruptures a segment of the main plate boundary fault that extends nearly the length of the country. The ground shakes strongly for several minutes, causing devastation that stretches from eastern Nepal to western Arunachal Pradesh. In India, the states of Sikkim, West Bengal, Assam and Arunachal Pradesh are badly affected. Nepal, China and Bangladesh also report deaths and injuries. One of the largest disaster relief operations in history begins. Figure 49 (following page) shows an estimated distribution of median shaking intensity for this hypothetical earthquake, provided by the USGS using their ShakeMap system. Thimphu is indicated by a black dot. The box indicates portion of the fault that ruptured to generate the earthquake. In Thimphu, the anticipated level of ground acceleration is very strong: it exceeds 1g, the acceleration due to gravity.

Buildings have collapsed across the country, with vulnerable traditional houses suffering some of the worst damage. In Thimphu, many modern reinforced concrete apartment buildings have collapsed at the ground storey, and bricks have fallen from the upper storeys of other buildings. Debris from collapsed buildings fully or partially blocks many major streets. Due to limited availability of heavy equipment, it will be many days before some streets are drivable.

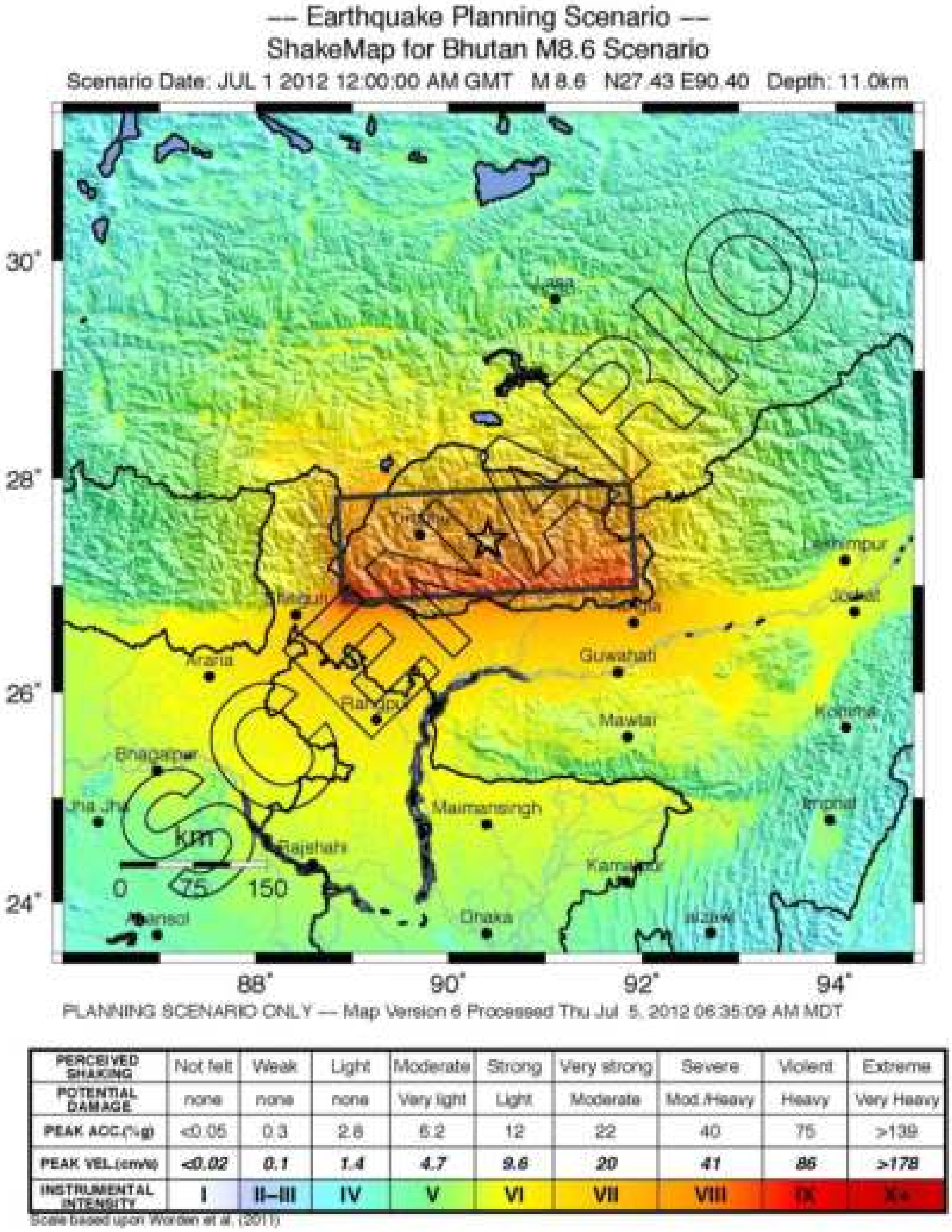


Figure 49. Median estimate of potential ground shaking intensity from M8.6 hypothetical scenario earthquake on the main plate boundary fault, courtesy USGS. The black box indicates the portion of the fault that ruptured during the earthquake.

Bhutan’s roads have been badly damaged by the earthquake. Massive landslides have buried the roads from Phuentsholing to Thimphu and Paro in multiple locations. These slides will take weeks to clear. The lateral road has also been badly affected by multiple large landslides. Smaller landslides and rockfalls have occurred all along the length of Bhutan’s highways. Bridges have failed in multiple locations.

Inside JDWNRH, strong shaking continues for about two minutes. Unrestrained supplies fall from carts and shelves, while tall and narrow shelves, racks and cabinets topple, and carts roll or tip over. Unanchored medical equipment tips over and breaks. Monitors fall from shelves in the wards. In the laboratories, bench-top equipment, glassware, samples and papers slide off benches and carpet the floor with broken glass, biohazard materials and chemicals. Many unreinforced brick partitions fall, especially in upper storeys. Once partitions fail, the suspended ceiling swings back and forth, breaking fire sprinkler pipes that leak water. As the shaking continues, suspended ceiling panels begin to fall.

The power fails, and the emergency generators and electrical equipment are damaged and do not come online. The mobile phone network goes down immediately. Landline phones are also down. In Thimphu, the telephone and mobile communication systems are likely to be offline for days to weeks. The staff at the hospital is unable to contact staff members who are offsite, their own families, or anyone else.

Many of the older unreinforced masonry buildings, including staff quarters, collapse. The main hospital building suffers major damage to brick infill walls and partitions but is structurally stable, except for the ramp wing, which is seriously damaged and judged unsafe. Bricks from these walls fall and injure nearby people, damage equipment, block corridors and create dust and debris. Extensive cracking in the brick infill walls and partition failures cause staff and patients to question the building's safety. Several floors in various wings are evacuated. Ramps and elevators are not available, and minor damage and debris in the stairwells makes movement of patients difficult. However, so many buildings have collapsed in Thimphu that the building looks good in comparison. Table 21 shows the damage states (defined in Table 1) that the evaluation team anticipates the M8.6 hypothetical scenario earthquake to cause.

Table 21. Likely damage states for hospital buildings in the M8.6 hypothetical scenario earthquake

Building Name	**Construction Type**	**Year Built**	**No. of Stories (incl. ground)**	**Likely Performance in M8.6 Hypothetical Scenario Earthquake** PGA 1g	
				Structure & Shell	Equip & Contents
New Main Hospital				S3	N3
Block A	RC w/brick infill	2008	5	S3	N3
Block B	RC w/brick infill	2008	6	S3	N3
Core	RC w/brick infill	2008	6	S3	N3
Block C	RC w/brick infill	2008	6	S3	N3
Block D – Ramp	RC w/brick infill	2008	5	S3	N3
Block E	RC w/brick infill	2008	3	S3	N3
Block F	RC w/brick infill	2008	6	S3	N3
Block G	RC w/brick infill	2008	6	S3	N3
Parking Garage	RC frame	2008	1	S4	n/a
Service Block/pharmacy	RC w/brick infill	2008	3	S3-S4	N3
Bridge from Service Block to Main Bldg.	RC frame	2008	2	S2	N3**
Filter Clinic and Old Bldg.					
Filter Clinic	RC w/brick infill	1997	3	S3	N3
Old Building main	Nonductile RC	1972 or	2	S3-S4	N3

	w/brick infill	later			
Old Building rear addn	Mixed*	1980s	2	S3-S4	N3
Community Heath					
Old Pediatric Ward	Nonductile RC w/infill	1980s	2	S3	N/A
Upper L-shape bldg.	URM*	2000s	1	S4	N/A
Hand Therapy Clinic	URM*	1980s	1	S4	
TB and vol. testing 66ldg..	URM*	1980s	1	S4	N/A
Psychiatric Ward (front)	URM*	1980s	1	S4	N/A
Psychiatric Ward (rear)	Nonductile RC w/infill	1980s	2	S3-S4	N/A
Health Help Center	Unreinforced brick	1970s	1	S4	N3
HIDD Office	URM*	1980s	1	S4	N/A
Maintenance Office	RC w/brick infill	1980s	2	S3	N/A
BMED Office	RC w/brick infill	1980s	1	S3	N/A
Staff Quarters					
MS Bungalow	Unreinforced brick*	1980s	1	S4	N/A
Doctors Bungalows	Unreinforced brick*	1980s	2	S4	N/A
Doctors Fourplexes	RC w/brick infill	1999	1	S3	N/A
Doctors Duplexes	Unreinforced stone masonry*	1980s	2	S3-S4	N/A
Nurses Type 1a 4-plex	RC w/block infill	1980s	2	S3	N/A
Nurses Type 1b 4-plex	Unreinforced stone masonry*	1980s	2	S4	N/A
Nurses Type 2 6-plex	RC w/brick infill*	1999	3	S3	N/A
Nurses Type 3 6-plex	RC w/brick infill	2001	3	S3	N/A
Nurses Type 4	Unreinforced brick*	1980s	2	S4	N/A
Central Medical Store	URM*	1997	1	S3	N3
Patient Guest House	RC w/URM infill	1992	2	S4	N/A

RC = reinforced concrete; URM = unreinforced masonry
* Exact construction material type and details are not known; assumed type is the most vulnerable of the likely construction material/structural system types. Vulnerability rating may improve if better, more earthquake-resistant construction can be verified.
** Pipes and services at joints

In the Service Block, which suffers severe structural damage, and may partially collapse, all three generators have fallen from their vibration isolators and are inoperable. Their mufflers and exhaust systems are damaged, the batteries have fallen, and the lines to the fuel tanks are broken. Diesel fuel spills onto the floor. The single wythe brick enclosures for the fuel tanks have collapsed. Electrical cabinets topple, and some of the unbraced wastewater pipes hanging from the ceiling above have broken and are leaking raw sewage. All of the unanchored medical gas cylinders topple and break their connections to the manifolds. The metal cylinders roll on the floor, hitting against each other and creating the possibility of a spark that could ignite the leaking oxygen. The unanchored tanks for the suction system topple. The unanchored boilers slide and break their pipe connections, leaking scalding water. Electrical cabinets containing control equipment topple. Many dangerous conditions exist in the building, and a post-earthquake fire is possible. The utilities crossing the services bridge and seismic joints inside the main hospital building are likely to break due to differential movement, rendering the distribution systems inoperable. The hospital's major utility systems will be offline for a significant period of time, perhaps several weeks, as replacement equipment is delivered and repairs are made. Table 22 shows the anticipated performance of the most important utility systems in the M8.6 hypothetical scenario earthquake.

Table 22. Likely performance of key utilities in M8.6 hypothetical scenario earthquake

System	**Likely Performance in M8.6 Hypothetical Scenario Earthquake**, PGA = 1g
Electric Power from off-site supply	Long interruptions of power should be expected
Electric Power from on-site generators	It is likely that none of the generators will be operational and the electrical equipment may also be damaged. Expect that power will not be available until emergency generators from off site are delivered and damaged equipment is repaired in an estimated 2-3 weeks or more.
Water from off-site system	Water supply damaged and not repaired for extensive length of time.
Water from on-site storage	
Fire suppression	Supply from tank and distribution system adequate for one fire incident. Tank could then be exhausted. Fire sprinkler piping likely to be damaged.
Domestic	Seven days of supply from tank will not be sufficient for length of time to repair off site system. Severe water rationing may be necessary, and emergency water will be needed to be provided from somewhere (tanker trucks, etc.)
Filtered Drinking	Filters will not be functional due to loss of power so water will need to be boiled or treated; drinking water will be limited by domestic supply; emergency water will need to be provided.
Communications	
Landline phones	Not operational for days to weeks, depending on damage and repair time
Mobile phones	Network unavailable for days to weeks, depending on damage to towers and infrastructure and repair time
112 System Call Center	Building may collapse, destroying equipment
Medical Gas	
Oxygen and Nitrogen	Not available. Resupply not available.
Suction	Probably not available. Compressors and or distribution system will not be functional. Tanks are not bolted down and likely to topple.

A torrent of injured people and their relatives, friends and neighbors begins to arrive at the hospital immediately after the earthquake. As the day progresses, more and more severely injured people are brought by family members and neighbors, who have rescued them from collapsed buildings. Gravely injured people arrive for days, as the military and police pull people from the rubble. With roads blocked and rural BHUs badly damaged or collapsed, families and friends of those injured in surrounding rural areas have no choice but to carry injured people to Thimphu on pack animals or on foot. Injured people continue to be brought to the hospital for up to two weeks.

Figure 50 below shows the anticipated performance of the hospital's buildings, in terms of functionality. The main hospital has not collapsed and has protected the lives of most inside, but a number of other buildings at the site may have collapsed. The hospital is able to provide austere care in the immediate post-earthquake period. The main building may be repairable, but the damage is extensive and full repairs would take months or longer.

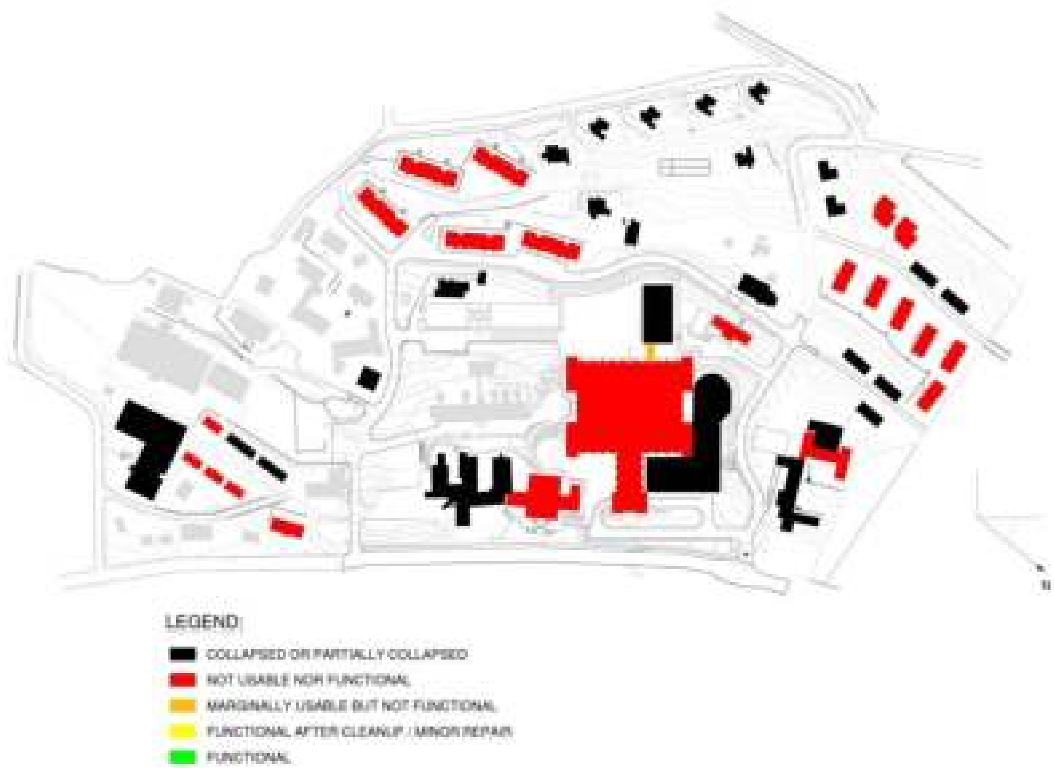


Figure 50. Likely performance of hospital buildings in M8.6 hypothetical scenario earthquake

Recommendations and Conclusions

Given the multiple seismic vulnerabilities and the likely damage and consequences resulting from a strong earthquake such as the M7 or M8.6 hypothetical scenarios described above, GHI strongly recommends immediate action be taken to begin improving the hospital's ability to deliver medical services following a major earthquake. Thimphu, and Bhutan as a whole, will depend on the hospital to provide lifesaving medical care in the earthquake's aftermath. A strong earthquake will damage the transportation systems linking Thimphu with India and the rest of the world and will likely cut off Thimphu from outside assistance and resupply for a significant period of time. The hospital will have to manage on its own in the crucial first hours and days after the earthquake, and it must prepare to do so.

Recommendations to Improve Seismic Performance

In order for a hospital to be functional following a major earthquake, the buildings must be useable; utility systems and medical equipment must be available; and the staff must be trained to respond effectively. The evaluation team recommends that JDWNRH take action in five key areas:

A. Setting functionality goals and planning to reach them;
B. Strengthening utility systems and backup capabilities;
C. Protecting critical medical equipment;
D. Improving physical safety and seismic performance of buildings; and
E. Preparing the staff to respond effectively.

In each of these areas, the evaluation team identified a number of specific mitigation actions to improve the hospital's earthquake performance, which are listed in the subsections below. Whenever possible, the team has provided guidance to help prioritize the recommended mitigation actions, according to their effectiveness in improving earthquake performance.

A. Setting Functional Goals and Planning to Reach Them

The evaluation team recommends the following specific mitigation actions:

1. Form a committee, with representatives from all departments, responsible for writing an emergency plan that considers not only earthquakes but all hazards that the hospital faces;
2. Develop an emergency plan that addresses continuity of operations and integration with the Health Sector Disaster Management and Contingency Plan, 2011;
3. Determine the level of performance expected from the facility: should the main hospital be functional following a massive earthquake on the plate boundary, or will it be acceptable to deliver medical care via field hospitals in open spaces near the building?;
4. Obtain estimates, from utility service providers, of the time required to restore service from offsite utilities following a set of possible earthquakes similar to those presented in this report;
5. Determine the length of time after a major earthquake for which the hospital should plan to be self-sufficient. Given Thimphu's geographic isolation from resupply sources, the length of time recommended in international standards may not be sufficient;
6. Arrange with HIDD for immediate safety inspection of hospital buildings, following an earthquake. Provide training for JDWNRH maintenance staff and HIDD engineers (if needed);
7. Develop an evacuation policy and procedures;
8. Work with HIDD and MoH to develop a long-term facilities improvement plan.

B. Strengthening Utility Systems and Backup Capabilities

Detailed recommendations for each major utility system are listed below.

Electrical system:

1. Anchor backup generators that supply emergency power, including the batteries and mufflers;
2. Provide additional fuel (adding another, larger tank would be one solution) sufficient to last the number of days deemed necessary, but five days minimum;

3. Connect the three existing storage tanks, so that fuel can be transferred from one to another;
4. Ensure that equipment and connections to grid power system are seismically robust;
5. Anchor all currently unanchored electrical cabinets at the base to prevent overturning;
6. Install better protection below plumbing in the Service Block ceiling, above electrical equipment;
7. Verify that electrical conduits crossing the service bridge and seismic joints in the main building can accommodate the expected amount of relative motion; install flexible connectors if needed.

Communications systems:

8. Obtain a backup communications system that does not rely on mobile phones;
9. Put in place simple communication procedures for emergencies, especially with Ministry of Health and responders (who will contact whom, etc.).

Water systems:

10. Based on estimate of time required to restore city water supply, improve emergency water supply by adding storage capacity, if needed;
11. Ensure that water filtration units in main hospital building are anchored;
12. Verify that flexible connectors are installed on fire sprinkler and domestic water pipes crossing seismic joints in the main building and service bridge; install flexible connectors if not present;
13. Laterally brace water pipes 60 mm (2 ½ inches) or larger that are suspended from the underside of floor slabs in the main hospital building;
14. Protect fire sprinkler drops from breakage, using methods that account for the performance and/or strengthening of suspended ceiling and partitions;
15. Anchor the hot water generator in the Service Block and ensure that any geysers elsewhere are not anchored to single wythe partitions.

Medical gas system:

16. Anchor oxygen and nitrous oxide cylinders in the Service Block. Select a restraint system that accommodates the need for frequent swapping out of cylinders;
17. Remove the space heater from the cylinder room;
18. Verify that flexible connectors have been installed on medical gas lines crossing seismic joints in the main building and the service bridge; install flexible connectors if not present;
19. Bolt tanks for the suction system down to the concrete slab.

Lifts, ramps and stairs:

20. Have a qualified structural engineer evaluate the lifts (which have presumably not been designed for earthquake loading) and recommend strengthening measures;
21. Anchor lift machinery and associated electrical equipment /cabinets, if unanchored;
22. Have a qualified structural engineer conduct a nonlinear analysis of the block of the main building (see item D.3) containing the ramp, and design measures to retrofit the columns

intersected by the ramp in order to prevent major structural damage, as well as to make the ramp useable;

23. Address vulnerability of the stairs as part of a larger analysis of the entire main hospital building.

Heating Ventilation and Air Conditioning (HVAC) systems:

24. Anchor boilers in the Service Block;
25. Supply flexible connectors on large pipes likely to be damaged by differential movement;
26. Seismically brace air handling units in the main hospital building, if not braced.

C. Protecting Critical Medical Equipment

The hospital needs to identify the most critical medical equipment and to determine whether or not it is adequately anchored/protected against seismic forces. The Bio-Medical Engineering Division maintains an inventory of medical equipment worth more than $2000 that could be ranked according to priority. An exhaustive list of recommendations for protecting all the hospital's critical medical equipment is outside the scope of this report, but such recommendations should include:

1. Anchor sterilizers to the floor to prevent toppling;
2. Install latches on blood bank refrigerator doors, and secure other equipment in blood bank;
3. Remount ceiling-mounted X-ray machine on rails connected to floor or ceiling, not partitions;
4. Secure laboratory bench-top equipment;
5. Design special anchorage, using non-metallic materials, for cabinet containing key supplies and coils in MRI room;
6. Rebuild and properly brace suspended ceiling in MRI control room (it has fallen several times);
7. Tether critical equipment stored in the hallway behind the operation theatres when not in use, to prevent damage caused by rolling into walls or other equipment, or by toppling;
8. When purchasing new equipment, include seismic anchorage as part of the contract;
9. Develop guidelines and appropriate methods for anchoring or restraining medical equipment, with BMED and equipment users;
10. Train BMED and maintenance staff to anchor and restrain equipment.

D. Improving Physical Safety and Seismic Performance of Buildings

Site and retaining walls:

1. Assess the stability and seismic vulnerability of the site's retaining walls;
2. Conduct a detailed site investigation to determine the geotechnical conditions and any potential hazards, including whether or not the new building was built partially on fill. As a first step, locate the reports of geotechnical investigations at the site and have an experienced geotechnical engineer review them.

Main hospital building:

3. Collapse or heavy damage of infill walls and partitions causes a loss of function in the adjacent spaces, as well as fear among occupants that the building may not be safe. If a decision is made

that the hospital should remain functional, then a qualified structural engineer should conduct nonlinear analyses (meaning computer analyses that include mathematical representations of the ways that the building's structural members become damaged), considering realistic, site specific ground motions, in order to determine the displacements and accelerations that design earthquakes are expected to cause, and to estimate the damage level of interior partitions and exterior walls. Such an analysis would also enable estimates of damage levels to the structural frame. The need, costs and benefits of strengthening could then be estimated.

4. Previous studies have indicated that single wythe brick partitions are likely to crack and fall perpendicular to their length, particularly if they are supporting equipment. Have a qualified structural engineer design a partition bracing system that satisfies infection control requirements, or replace single-wythe brick partitions in critical areas (such as OTs, NICU, etc.) with lightweight partitions.

5. Brace suspended ceilings in critical areas;

6. Movement of people, equipment and supplies from one floor to another will be very difficult given the anticipated damage to the ramps, stairs and lifts in the largest earthquake; investigate these vertical transportation systems as part of the analyses described in the bullet point above.

7. Mitigate the captive columns in the parking garage by cutting a slot at the edge of the masonry wall and decorative *Zhu* where they intersect the column, to allow deformation to occur, and fill the resulting gap with elastomeric material;

Service block:

8. Have a qualified structural engineer conduct a nonlinear analysis and prepare a retrofit scheme to reduce the chances of ground storey collapse in a severe earthquake.

Bridge connecting main hospital and service block:

9. Provide flexible connectors for medical gas pipes and conduits at the junctions between the bridge and the main hospital building and Service Block, to permit the buildings and bridge to move separately during an earthquake without damaging the pipes and conduits.

10. Have a qualified structural engineer assess the structural safety of the bridge.

Other buildings:

11. Use planned capital improvements over successive five year plans as opportunities to replace older vulnerable buildings with seismically safer new ones;
12. Retrofit or replace the MS quarters and doctors' bungalows;
13. Replace the ambulance drivers' quarters;
14. Replace the BMED, HIDD and Maintenance office buildings, perhaps with a single new building containing offices for all three organizations;

15. Conduct structural analyses of the reinforced concrete staff quarters (doctors' fourplexes and both types of 6-unit nurses' quarters) to verify that they provide life safety for the expected level of ground shaking in a major earthquake;
16. Replace the most vulnerable community health buildings or move the community health departments off-site to safer buildings;
17. Move the Health Help Center off-site to a newly built Emergency Operations Center designed to remain operational during the strongest expected earthquakes;

E. Preparing the Staff to Respond Effectively

1. Ensure that all staff are familiar with the hospital's emergency plan and know their role in it;
2. Provide earthquake safety training for staff;
3. Provide specialized training in building safety assessment for Maintenance and HIDD engineers as needed;
4. Help staff members to prepare personally (family emergency plans, anchoring potentially hazardous items in the home, etc.), so they will be better able to work following an earthquake;
5. Establish recurring training, so that new staff members receive emergency preparedness and earthquake safety training;
6. Test specific aspects of the emergency plan with regular drills (i.e., fire);
7. Test the broader emergency plan with simulation exercises.

The assessment team recommends that the hospital implement the mitigation measures discussed above, according to the priorities in Table 23. GHI also suggests that any of the recommended mitigation measures that can be easily accomplished should be done as soon as possible, regardless of the priorities set in the table.

Table 23. Suggested priorities for mitigation measures to address vulnerabilities

Mitigation Measure	Number	Priority Level (1 Highest)
Anchor emergency generator	B.1	1
Increase emergency generator fuel supply	B.2, B.3	1
Provide backup communications	B.8, B.9	1
Develop emergency plan	A.1, A.2	1
Train staff	E.1-E.3	1
Set functional goals and develop facilities improvement plan	A.3-A.8	2
Protect drinking water filters	B.11	2
Obtain site geotechnical information and take action if retaining walls are critical	D1, D2,	3
Anchor other parts of electrical system	B.4, B.5	3
Anchor sterilizers and seismically protect other critical medical equipment	C.1-C.10	3
Anchor boilers and hot water generator	B.14, B.23	3
Protect supply of medical gases	B.16-B.17, C.19	3
Expand emergency water supply	B.10	4
Provide reliable vertical transportation within hospital (lifts, ramps, stairs)	B.20-B.23,	4

	D.6	
Improve stability of interior partitions	D.4	4
Retrofit suspended ceilings as required based on study of interior partitions	D.5	5
Retrofit fire sprinkler drops as required based on study of interior partitions	B.14	5
Provide flexible connectors for services crossing seismic joints and other areas where differential movement expected	B.7,12,18, B.25, D.9	5
Brace air handling units	B.26	6
Analyze main building, service building and bridge to determine performance	D.7-D.10	6

The recommended mitigation measures and priorities must be weighed with practicality and costs. Although these are considerations in Table 23, the evaluation team does not have complete knowledge of the immediate availability of resources or funding processes.

Overall, the team's highest priority recommendations are to:

- Strengthen the hospital's backup utility systems, especially the electrical power system, and protect the hospital's critical medical equipment. Simple, cost-effective measures taken now will substantially increase the hospital's ability to remain functional after a strong earthquake;
- Write an emergency plan that provides guidance for hospital operations following a damaging earthquake affecting Thimphu, and test it with a scenario-based exercise involving ministries responsible for health, transportation and utilities;
- Develop a long-term facilities improvement plan to replace or retrofit buildings that do not meet seismic performance goals, especially those vulnerable to collapse or life-threatening damage;
- Train staff to respond effectively following an earthquake.

Conclusions

Jigme Dorji Wangchuck National Referral Hospital (JDWNRH) is part of Bhutan's medical delivery system, which includes treatment at outreach clinics and Basic Health Units, district hospitals and regional referral hospitals and which requires communications as well as transportation, medical professionals and equipment. Emergency medicine is dependent on facilities, but also on people, utilities and transportation systems that are not directly part of the medical delivery system. The performance of JDWNRH during earthquakes should be evaluated in the context of the broader medical system and critical community services. This evaluation should be done periodically, because conditions and knowledge change.

This report only considers the buildings and other facilities at JDWNRH, the most important medical facility in Bhutan. However, this report goes beyond simply classifying the damage potential of buildings and systems to address consequences, and also introduces three scenarios, or postulated earthquake events.

The JDWNRH is vulnerable to earthquakes in many ways, but it also has inherent strengths (including a recently built main building) that should make it possible for the hospital, by implementing a number of reasonable mitigation measures, to remain at least minimally functional following all but the largest anticipated earthquakes. With more extensive investment in seismic upgrades, the hospital should be able to continue delivering essential medical services even in very large earthquakes, such as the M8.6 hypothetical scenario earthquake considered in this report.

The hospital's ability to function depends on several interdependent off-site transportation and utility systems, which are beyond the scope of this report. The effects of disruptions to these systems increase, the longer that the disruptions continue. For example, JDWNRH has emergency generators, but the fuel supply is limited and the resupply route is vulnerable to blockages. Electric power, generator fuel, communication systems, water supply and road transportation are interdependent, and critical to a functioning emergency medical system. Thus, hospital functions depend on restoring the power grid quickly and on opening supply routes for fuel, additional supplies and medicines, and to transport patients. For this reason, GHI recommends that the hospital test its emergency plan and backup capabilities by conducting a scenario exercise with a timeline that extends one month after a major earthquake, and which involves not only the Ministry of Health but also the ministries responsible for the transportation systems and utilities upon which the hospital depends.

GHI recommends that JDWNRH begin working immediately to improve the facility's performance. The mitigation and preparedness measures necessary to help keep the hospital functional will take time to implement, and will need to be planned and phased over a number of years. However, the hospital can make major improvements within several years. The hospital will then be much better prepared to serve the people of Thimphu when the next earthquake strikes.

Finally, GHI recommends that the Ministry of Health critically evaluate the post-earthquake functionality of the nation's emergency medical system, including other facilities and the interdependent system of utilities and roads.

Appendix A – Tables Summarizing Performance States for Hypothetical Scenario Earthquakes

Table 24. Performance of buildings in hypothetical scenario earthquakes

Building Name	**Construction Type**	**Year Built**	**No. of Stories (incl. ground)**	**Likely Performance in Hypothetical Scenario Earthquake** (Structure and shell left; equipment, pipes, & contents center, functional color code right)								
				Moderate M6.1			Major M7			Severe M8.6		
				PGA 0.25g			PGA 0.58g			PGA 1g		
				Utilities available			Utilities extremely limited			Utilities not available		
				Struct	Equip	Code	Struct	Equip	Code	Struct	Equip	Code
New Main Hospital												
Block A	RC w/brick infill	2008	5	S1	N1		S2	N2		S3	N3	
Block B	RC w/brick infill	2008	6	S1	N1		S2	N2		S3	N3	
Core	RC w/brick infill	2008	6	S1	N1		S2	N2		S3	N3	
Block C	RC w/brick infill	2008	6	S1	N1		S2	N2		S3	N3	
Block D - Ramp	RC w/brick infill	2008	5	S1	N1		S3	N2		S3	N3	
Block E	RC w/brick infill	2008	3	S1	N1		S2	N2		S3	N3	
Block F	RC w/brick infill	2008	6	S1	N1		S2	N2		S3	N3	
Block G	RC w/brick infill	2008	6	S1	N1		S2	N2		S3	N3	
Parking Garage	RC frame	2008	1	S1	n/a		S3	n/a		S4	n/a	
Service Block/ pharmacy	RC w/brick infill	2008	3	S1	N2		S2	N2		S3-S4	N3	
Bridge from Service Block to Main Bldg.	RC frame	2008	2	S1	N1**		S1	N2-N3**		S2	N3 **	
Filter Clinic and Old Bldg.												
Filter Clinic	RC w/brick infill	1997	3	S1	N1		S2	N2		S3	N3	
Old Building main	Nonductile RC w/brick infill	1972 or later	2	S2	N1		S3	N2		S3-S4	N3	
Old Building rear addn	Mixed*	1980s	2	S2	N2		S3	N2		S3-S4	N3	
Community Heath												
Old Pediatric Ward	Nonductile RC w/infill	1980s	2	S1-S2			S2			S3		
Upper L-shaped bldg.	URM*	2000s	1	S2			S3			S4		
Hand Therapy Clinic	URM*	1980s	1	S2			S3			S4		
TB and vol. testing bldg.	URM*	1980s	1	S2			S3			S4		
Psychiatric Ward (front)	URM*	1980s	1	S2			S3			S4		
Psychiatric Ward (rear)	Nonductile RC w/infill	1980s	2	S2			S3			S3-S4		

Table 24. Performance of buildings in hypothetical scenario earthquakes (continued)

Building Name	**Construction Type**	**Year Built**	**No. of Stories (incl. ground)**	**Likely Performance in Hypothetical Scenario Earthquake** (Structure and shell left; equipment, pipes, & contents center, functional color code right)								
				Moderate M6.1			Major M7			Severe M8.6		
				PGA 0.25g			PGA 0.58g			PGA 1g		
				Utilities available			Utilities extremely limited			Utilities not available		
				Struct	Equip	Code	Struct	Equip	Code	Struct	Equip	Code
Health Help Center	Unreinforced brick	1970s	1	S2	N2		S3	N3		S4	N3	
HIDD Office	URM*	1980s	1	S2			S3			S4		
Maintenance Office	RC w/brick infill	1980s	2	S2			S2			S3		
BMED Office	RC w/brick infill	1980s	1	S2			S2			S3		
Staff Quarters												
MS Bungalow	Unreinforced brick*	1980s	1	S2			S3			S4		
Doctors Bungalows	Unreinforced brick*	1980s	2	S2			S3			S4		
Doctors Fourplexes	RC w/brick infill	1999	1	S1			S2			S3		
Doctors Duplexes	Unreinforced stone masonry*	1980s	2	S2			S3			S3-S4		
Nurses Type 1a 4-plex	RC w/block infill	1980s	2	S1			S2			S3		
Nurses Type 1b 4-plex	Unreinforced stone masonry*	1980s	2	S2			S3			S4		
Nurses Type 2 6-plex	RC w/brick infill*	1999	3	S1			S2			S3		
Nurses Type 3 6-plex	RC w/brick infill	2001	3	S1			S2			S3		
Nurses Type 4	Unreinforced brick*	1980s	2	S2			S3			S4		
Central Medical Store	URM*	1997	1	S2	N2		S3	N3		S4	N3	
Patient Guest House	RC w/URM infill	1992	2	S2			S3			S4		

RC = reinforced concrete; URM = unreinforced masonry
* Exact construction material type and details are not known; assumed type is the most vulnerable of the likely construction material/structural system types. Vulnerability rating may improve if better, more earthquake-resistant construction can be verified.
** Pipes and services at joints

Table 25. Performance of key utilities in hypothetical scenario earthquakes

System	**Likely Performance in Hypothetical Scenario Earthquake**		
	Moderate M6.1 PGA = 0.25g	Major M7 PGA = 0.58g	Severe M8.6 PGA = 1g
Electric Power from off-site supply	May be short interruption of power	Interruptions of power are likely to be longer than 24 hours	Long interruptions of power should be expected
Electric Power from on-site generators	One or more of three emergency generators should be available. Emergency fuel supply should be adequate.	Generators and associated equipment may be damaged but one generator may be operational so power should be available. Length of time is limited to use of only one of the three fuel tanks. Fuel could be siphoned or pumped from other tanks to provide 50 hours of power. Additional fuel may not be available.	It is likely that none of the generators will be operational and the electrical equipment may also be damaged. Expect that power will not be available until emergency generators from off site are delivered and damaged equipment is repaired in an estimated 2-3 weeks or more.
Water from off-site system	Water supply may be disrupted, but could be repaired prior to exhaustion of on-site tank.	Water supply probably disrupted and could take days to reestablish.	Water supply damaged and not repaired for extensive length of time.
Water from on-site storage			
Fire suppression	Supply from tank and distribution system adequate.	Supply from tank and distribution system adequate for one fire incident. Tank could then be exhausted.	Supply from tank and distribution system adequate for one fire incident. Tank could then be exhausted. Fire sprinkler piping likely to be damaged.
Domestic	Supply from tank and distribution system adequate	Seven days of supply from tank may not be sufficient for length of time to repair off site system. Water rationing may be necessary.	Seven days of supply from tank will not be sufficient for length of time to repair off site system. Severe water rationing may be necessary, and emergency water will be needed to be provided from somewhere (tanker trucks, etc.)
Filtered Drinking	Likely to be adequate; depends on availability of power and proper anchorage of filter units to prevent earthquake damage.	Supply limit as per domestic water. Power may not be available if off site power is not repaired before generator fuel exhausted.	Filters will not be functional due to loss of power so water will need to be boiled or treated; drinking water will be limited by domestic supply; emergency water will need to be provided.

Table 25. Performance of key utilities in hypothetical scenario earthquakes (continued)

System	**Likely Performance in Hypothetical Scenario Earthquake**		
	Moderate M6.1 PGA = 0.25g	Major M7 PGA = 0.58g	Severe M8.6 PGA = 1g
Communications			
Landline phones/ switchboard	Probably operational	Service probably interrupted	Not operational for days to weeks, depending on damage and repair time
Mobile phones	Network unavailable for several hours	Network unavailable for hours to days	Network unavailable for days to weeks, depending on damage to towers and infrastructure and repair time
112 System Call Center	May be operational with emergency power from hospital generators;	Operation limited to length of time power is available from hospital and whether internet connectivity is available; system offline initially until equipment can be reconnected; usage limited by disruptions to phone systems and internet.	Damage to equipment and loss of power from hospital keeps system offline for weeks;
Medical Gas			
Oxygen and Nitrogen	Rack for cylinders is available but cylinders not anchored. Cylinders will fall over and rupture at least some of the piping. Could be down for 1 day until staff can straighten it up and reconnected.	Cylinder room will be in a considerable state of disruption. It could take several days to repair. Resupply from off campus may not be available.	Not available. Resupply not available.
Suction	Available	Probably available. Compressors are robust. Need power and distribution system, including tanks to be functional	Probably not available. Compressors and or distribution system will not be functional. Tanks are not bolted down and likely to topple.