



A Safer Tomorrow?

Effects of a Magnitude 7 Earthquake on Aizawl,
Mizoram and Recommendations to Reduce Losses

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Disclaimer

The scenario described in this document is not a prediction. Rather, it is a hypothetical narrative describing what could happen in the event of an earthquake in Aizawl. A real event may be significantly different.

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As part of our partnership with the Mizoram Department of Disaster Management and Rehabilitation (DM&R), GeoHazards International (GHI) and GeoHazards Society (GHS) wrote this scenario and facilitated a process of consultation with local professionals to develop the recommendations in this document. We are grateful for the support of Mr. P. C. Lallawmsanga, Principal Secretary, DM&R, and his staff, and for the assistance provided by dedicated professionals from Aizawl Municipal Council, Aizawl Development Authority and numerous agencies of Government of Mizoram (GoM), including Public Works (PWD), Public Health Engineering (PHED), Power and Electricity, Mizoram Remote Sensing Application Center (MIRSAC), and Directorate of Geology and Mineral Resources (DGMR), who are too numerous to mention by name. They worked together with us for more than a year, and continually inspire us with their dedication and passion for a safer Aizawl.

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What is an Earthquake Scenario?

In the pages that follow, we present an *earthquake scenario* for Aizawl. A scenario tells the story of a realistic, but hypothetical, earthquake and its estimated impacts. It is not a prediction. It will help you visualize specific impacts and decide what to do. We want to help you, and all the people of Aizawl, plan for safe outcomes. As you read, we encourage you to imagine yourself living the scenario, and ask:

- Where will I be?
- Where are my children, my spouse, my parents?
- What are my responsibilities? Can I fulfill them?

Picture What Might Happen to You in this Scenario

It is 2 PM on a weekday when a magnitude 7.0 earthquake strikes Aizawl. Centered on a fault 10 km northwest of Aizawl and 30 km deep, the earthquake is not the largest that could happen, but it is large enough to do tremendous damage. The shaking lasts about 30 seconds. In that brief period of time, it changes Aizawl forever.

The shaking collapses thousands of buildings, sends hundreds of landslides thundering down slopes, and throws brick walls, water tanks and pieces of buildings down onto streets and paths. The noise is deafening. Where can you find safety? Everything is moving; everything is falling. You slide under a table and hold on. Fortunately your building remains standing, but many do not. When the shaking stops, a thick, choking cloud of dust created by collapsed buildings rises over the city. More than 19,000 Aizawl residents have been killed immediately by building collapses, landslides and falling bricks. You have made choices about the safety of your home or workplace that have helped you survive: your house was designed and built to resist earthquakes, is not in a zone of very high landslide hazard, and you have taken care not to destabilize the slope.

As the dust begins to clear, you emerge from your home or workplace to a changed city. Debris from more than 14,000 collapsed buildings blocks streets and paths. Older reinforced concrete buildings, constructed before Aizawl Development Authority (ADA) and Aizawl Municipal Council (AMC) building regulations went into effect, have collapsed and killed the most people. Some buildings have fallen downhill and caused those below to fall as well. Landslides triggered by the earthquake have severed roads and water mains, and have swept away electrical poles. There is no power, no water, and no mobile phone service. Though you don't know it yet, most of Aizawl's communications and transportation links with the rest of India and the world are cut off.

Your elderly neighbor is seriously injured, and you and a family member decide to take her to the hospital. Though the shaking has made a mess of your kitchen, you quickly locate a bag and fill it with a few bottles of water, snacks, and blankets, knowing that these will be in short supply. After an arduous 3-hour journey on foot around piles of debris and crushed cars you reach the hospital, only to find chaos. Though the main building still stands, the interior of the hospital is badly damaged, and people are crammed into the parking areas outside. Doctors and nurses are trying to treat the injured with whatever supplies and equipment they could pull out of the hospital, but supplies are completely inadequate for the number of injured. Nurses are dividing patients into three categories: those who will not be treated because their injuries though painful are not severe; those who will not be treated because their injury is so severe

that they will die regardless; and those who will be treated as help becomes available. Decisions are difficult and upsetting to all involved. Family members of those not treated find it hard to accept these decisions, and police must move them away so the nurses can continue to work. Your neighbor survives the trip to the hospital and is placed in the third group that eventually receives care, but many do not. Six thousand more people will die from a lack of timely medical care, bringing the total number of deaths to more than 25,000. It is now dark and the journey home is completely impossible without light, so you sleep outside the hospital in the only empty space you can find.

In the meantime, your spouse has made a similarly difficult journey to your children's school as planned in your family's preparedness plan. There is chaos outside as parents try to find their children. The government school building, designed by an engineer and built to resist earthquakes, withstood the shaking without collapsing. Long before the earthquake, the teachers prepared and trained the students on what to do. Because the engineer, the builder, and the teachers chose to prepare for an earthquake, your children survived. Your spouse finds them, frightened but safe.

In the days that follow the earthquake, the situation becomes increasingly dire. Food and cooking gas begin to run out. Helicopters—the only way in and out of the city—are busy bringing rescuers in and taking the badly injured out. You have a family emergency kit with stored water and food, which helps somewhat. You and your family—finally reunited—help neighbors in any way you can, but if more aid does not arrive soon, your children will not have enough to eat. You begin to consider how you and your family might leave the city and return on foot to your parents' home village, but due to the lack of communication you do not know whether that village also suffered damage. Because of badly damaged and collapsed buildings, more than half of the city's residents do not have a safe place to live. It takes months just to clear the debris. Recovery will be so long and painful that the majority of residents will leave over the course of the coming weeks and months. Aizawl will never be the same.

Aizawl's Choice

The choices you have made and will make—regarding whether your home is resistant to earthquakes, whether your home is on stable land, and how you have prepared your family—in large part determine your chance of survival when an earthquake strikes Aizawl.

Today, Aizawl stands at the threshold of major growth, with a master plan that sees the population doubling in the next 20 years. The choice the Aizawl community faces is a serious one. Your city can choose to build safely, to avoid destabilizing the land, and to reduce the risk presented in this scenario. Or it can let development proceed with building practices that increase risk. If Aizawl makes only marginal improvements, your capital city will face devastation when a major earthquake strikes. We urge you to choose for the future and invest now in a safe, thriving city.



Contents

What is an Earthquake Scenario?	iii
Picture What Might Happen to You in this Scenario	iii
Aizawl's Choice	iv
Introduction.....	1
How Earthquakes and Landslides Occur in Aizawl	1
How Experts Forecast Earthquakes.....	2
How this Scenario Can Help Aizawl Plan for the Future	2
High Level Recommendations.....	3
Scenario Contents	4
The Scenario Event.....	5
The Earthquake	5
Earthquake Shaking.....	6
Hazards Triggered by Earthquakes.....	8
Earthquakes Trigger Landslides.....	8
Earthquakes Ignite Fires.....	11
Earthquakes Create Hazards from Falling Objects Inside and Outside of Buildings	11
Damage to the City of Aizawl.....	12
Building Damage Caused by Shaking and Landslides.....	12
Individual Building Damage Caused by Shaking.....	12
Individual Building Damage Caused by Landslides	13
Important Buildings.....	13
Multiple-building Collapses	14
Total Expected Damage to Buildings	14
Damage to, Utilities, Communications and Transportation Systems Caused by Shaking and Landslides.....	15
Water System.....	17
Wastewater	18
Electrical System	18
Communications Systems	19
Transportation Systems.....	21
Fuel Delivery	23
Consequences of Damage and Impacts on the Community	24
Human Casualties	24
Disruptions from Building Damage.....	26

Utility Breaks and Interruptions	26
Disruption to Critical Medical Care	26
A Local Example of Earthquake Impacts: Case Study of Electric Veng Locality	28
Emergency Response and Recovery	31
Emergency Response following the Scenario Earthquake	31
Day One	32
Day Two	35
One Week	36
Two Weeks	37
Recovery and Economic Impact	37
One Month.....	38
Three Months	38
Six Months.....	38
One Year.....	38
Actions to Improve Earthquake Safety and Resilience	39
What Can Aizawl's Leaders Do to Prepare?	39
What Can I Do?	40
Detailed Recommendations	41
Appendices	57
A: Earthquake Sources and Shaking	
B: Landslides	
C: Buildings	
D: Infrastructure	

Introduction

When most Mizo people lived in traditional timber homes on the tops of ridges, earthquakes could do little harm. The lack of reports about past earthquake disasters may be incorrectly interpreted as implying that earthquakes are infrequent in Aizawl. Actually, the city is located in an area of high seismic hazard, meaning that a damaging earthquake might soon strike this young city. How will it affect Aizawl's known landslide risk? How will it impact buildings and infrastructure? How will it impact people? How can the community lessen the consequences of such an earthquake? This scenario and report, developed by a team of local and international experts, explains the consequences of a plausible, medium intensity earthquake and how the city can reduce future earthquake and landslide damage and its consequences.

The scenario describes the foreseeable damage and consequences of a plausible but hypothetical magnitude 7 (M7) earthquake on Aizawl. It also shows impacts to certain roads, villages and the Lengpui airport, which fall outside the Aizawl Municipal Council boundary in the State of Mizoram's jurisdiction. The report describes specific actions that will help the people of Aizawl reduce the damage caused by earthquakes and landslides and its consequences. Recommendations include improvements to infrastructure, development policies and plans, building design and construction, emergency planning and preparedness, and response capabilities.

How Earthquakes and Landslides Occur in Aizawl

Aizawl will always face a risk of earthquakes. The scenario earthquake originates on a fault approximately 10 kilometers northwest of the city. There are many fault segments near Aizawl— even some under the city—that could cause damaging earthquakes of M7 or greater. Earthquakes can occur on faults lying to the north, south, west or east. They can be of smaller or greater magnitude, on faults that lie deeper or near to the ground surface, farther away or closer. It is possible for a huge plate boundary fault that underlies parts of Bangladesh and northeast India to rupture, as it is inferred to have done numerous times in the past. While earthquakes on this fault would be huge and devastating, the chance of a great earthquake occurring is much less than the chance of moderate earthquakes striking nearby.

Hills and valleys provide evidence of on-going geologic processes that bend and buckle the layers of rock beneath the city, shaping the landscape, and also causing earthquakes. The steeply sloping beds of sandstone and shale that underlie Aizawl, which are exposed throughout the city, were once horizontal layers of sediment on the ocean floor. The tremendous forces necessary to uplift Aizawl's high ridges result from the Indian subcontinent colliding with the rest of Asia and squeezing northeast India against Myanmar and China. Instruments that monitor the relative movement of the ground surface using satellites show that the Indian subcontinent continues to move northward into the rest of Asia at several centimeters per year (about as fast as fingernails grow). This process places tremendous pressure on the underlying rock, which deforms elastically and stores the pent-up energy until it is released by sudden shifts along weak shear surfaces called *faults*. These *fault ruptures* cause violent jolts that radiate seismic waves through the solid earth and shake the surface in what is known as an earthquake.

The size (magnitude) of the earthquakes in northeast India varies over a wide range. Most are small earthquakes that are detected only by instruments. Occasionally a larger earthquake causes perceptible ground shaking and damage. Some earthquakes are huge and cause widespread damages. In geologically active areas such as the Burma Ranges where Aizawl is located, small earthquakes are common, and some large damaging earthquakes are described in the historic record. After each earthquake, elastic strain starts building up, and the cycle leading to the next earthquake begins anew. Throughout the region, this process has been repeated countless times to build mountain ranges and will continue far beyond our grandchildren's lifetimes to gradually transform the shape of the land surface.

Aizawl also experiences frequent landslides on its many slopes. Heavy rainfall can trigger them, as can excavations that undermine slope stability. Earthquakes, however, present the most dangerous landslide risk: even moderate earth shaking can trigger hundreds of landslides all at once.

How Experts Forecast Earthquakes

Since producing the last damaging earthquake, a fault may have built up energy to the point where a similar damaging earthquake could occur again at any time. While the precise location, time and size of future earthquakes cannot be predicted, earthquakes occur in predictable locations and at intervals that can be estimated from the size of the maximum magnitude or the size of the fault and from the long-term rate of slip. Aizawl is affected by several different faults, so that the probability of damage from earthquakes must combine the contributions from each of these fault systems. Earthquakes also affect buildings, infrastructure and people in foreseeable ways. Scientists, engineers and emergency management professionals can anticipate the location of faults, what size earthquakes such faults can generate, how strong the shaking may be, how earthquakes trigger landslides, and how buildings, roads, pipelines and utility systems perform. These professionals can describe potential losses and consequences.

To develop the scenario M7 earthquake in Aizawl, a team of earth scientists, engineers and planners from Mizoram and from elsewhere in India and the United States, local government officials and leaders contributed professional knowledge as well as experience gained during earthquakes and landslides. Earth scientists described the geologic forces that cause earthquakes, the nature of faulting, and the strength of shaking. Geologists reviewed geologic structure, geomorphology, and existing landslides, and then estimated amount of landsliding likely to occur. Engineers, relying on analysis and experience from observing earthquake damage in India and elsewhere, estimated how buildings would shake and fail. The team determined how landslides and building damage would harm people; damage water, electricity and communications utilities; and block roads. The team estimated casualties, based on observations from other earthquakes and professional judgment. The consequences derive from past earthquakes experiences and knowledge of local participants. For brevity in this report, "we" means the team members who contributed data and wrote the scenario, and who made recommendations to minimize damage.

How this Scenario Can Help Aizawl Plan for the Future

This report, *A Safer Tomorrow? Effects of a Magnitude 7 Earthquake on Aizawl, Mizoram and Recommendations to Reduce Losses*, presents foreseeable losses and consequences from a hypothetical earthquake near Aizawl. We determined that a plausible M7 earthquake would cause extensive damage, destroy buildings, render useless utility systems and roads, cause

thousands of casualties, interrupt lives, and set back Mizoram's economic development. The shaking would trigger hundreds of landslides, causing new slides and reactivating existing ones. The recovery process would take years. Some families and businesses would never recover. Mizoram and Aizawl would change drastically. The scenario reflects what would happen if the M7 earthquake were to strike today.

Aizawl *can* avoid the dire consequences presented in this scenario. By implementing the recommendations presented here, Aizawl can considerably reduce the damage and consequences from such an earthquake. This scenario provides insights into the needs following an earthquake and informs plans to prepare and respond effectively to an earthquake disaster. More important, the report describes measures that people, organizations, and the government can take to reduce existing risk and plan for a more robust, more resilient Aizawl. Damage and casualties create unprecedented demands for medical care, rescue operations, food and water. Understanding losses, their implications and what can be done to reduce them provides homeowners, businesses and government agencies with the information and motivation to take action. This scenario and recommendations, and the planning that follows, will provide a roadmap to safety.

Aizawl is located in an earthquake zone, but being a very young city it has not yet experienced a destructive earthquake. Nevertheless, knowledge about the threat exists and will improve over time.

Read this scenario and consider how an earthquake would affect you, your family and your community, your responsibilities to care for them, and your livelihood. Use the information to think about what *you* will do to improve the situation. Discuss this report with your family and friends, with your co-workers and colleagues in offices, schools, community organizations and church groups. Decide together what you can do, because even small measures can save lives. Aizawl is in a race with time. How much can we accomplish, together, before a damaging earthquake strikes?

High Level Recommendations

Working with local agencies, we developed a set of recommendations to help make Aizawl safer and reduce the tremendous damage and loss of life that will occur if nothing is done. The highest priority city-wide recommendations include:

- regulate slope cutting that makes slopes unstable;
- provide a comprehensive rainwater and wastewater drainage system to help prevent rain-triggered landslides;
- enforce and encourage the public to follow the AMC building regulations to help prevent building collapses in an earthquake;
- prevent land allocation and development in areas of high landslide hazard; and
- obtain and use more detailed geologic maps to better define and manage hazardous areas.

In the sections following the scenario, we provide a detailed description of our recommendations, outlining a number of specific steps to improve earthquake and landslide safety in Aizawl.

Together, Aizawl's residents and technical professionals can make meaningful improvements in safety in the coming years. We hope that this scenario will help you to better understand the risks Aizawl faces, and to identify what *you* can do to help.

Scenario Contents

The scenario that follows describes the hypothetical earthquake, the intensity of shaking in Aizawl, the effect of shaking on buildings and infrastructure, the landslides triggered by the shaking and their effects on infrastructure and buildings, the effects of damage on people, and the implications for emergency response and for long-term recovery. In each section, the scenario's immediate effects are described in italics. Recommendations to help Aizawl avert the disastrous consequences the scenario describes comprise a separate section following the scenario description. Four appendices provide additional technical information and describe the assumptions and methods we used.

The Scenario Event

The Earthquake

At 2 PM on a weekday, a magnitude 7.0 earthquake occurs on an unnamed strike-slip fault centered approximately 10 kilometers northwest of the city, and 30 km below the surface. Figure 1 shows the earthquake's source – the portion of the fault that breaks, called a rupture plane – with respect to Aizawl. At 2 PM children are at school, people are at work, roads are busy, and government officers are at their desks. Four hours of daylight remain.

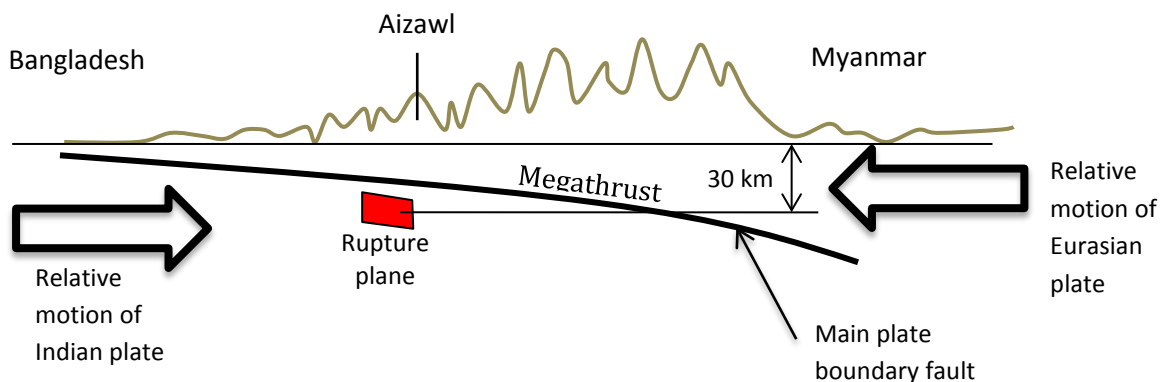


Figure 1. Schematic East-West cross section through the Earth's crust showing the location of the rupture plane (in red) that is the source of the M7 scenario earthquake. Topography is exaggerated. (After Seeber)

While hypothetical, this scenario earthquake is in a zone where smaller earthquakes occur frequently. The hypothetical M7 source is realistic, reasonable, and based on current scientific knowledge. Seismologists have observed earthquakes of this type in other parts of northeast India with similar geology. Earthquakes that would have far more damaging effects in Aizawl are possible from other fault sources. Earthquakes affecting Aizawl can be much larger or closer to the surface, and can occur directly under the city. [Appendix A: Earthquake Sources and Shaking](#) describes the source of the scenario earthquake as well as other faults that can generate damaging earthquakes affecting Aizawl.

This scenario describes a reasonable set of consequences from a plausible moderately large earthquake. The effects of a real earthquake, however, which could occur on any of these faults at any time of day, may be more severe or less severe than what we present in this scenario. Though the scenario describes a daytime earthquake, an earthquake could happen at night when people, including government officials, are at home, or on Sunday while most are attending church services.

A large damaging earthquake is usually the “mainshock” of an earthquake sequence that includes many smaller aftershocks. They will occur both on the same fault that produced the mainshock and on other related faults, as the earth adjusts to changed conditions. Several aftershocks with damaging magnitudes are likely within the first few weeks. The frequency of aftershocks would gradually diminish with time but an enhanced likelihood of a large nearby earthquake would persist for years after the mainshock.

Earthquake Shaking

The earthquake shaking—and the landslides triggered by shaking—cause the majority of the expected damage in Aizawl. The back-and-forth ground motion caused by the earthquake generates large forces and displacements in buildings, bridges, pipes, tanks, retaining walls, and communication towers. Many of these structures fail because they were not designed to withstand such forces and displacements.

The scenario earthquake causes ground accelerations in Aizawl of approximately 35 percent of the acceleration due to gravity (0.35g). The scenario ground acceleration is similar to that prescribed by the building code (Indian Standard 1893) for engineering design in Seismic Zone V, and is also similar to the levels anticipated by several recent studies¹. This level of shaking is strong enough to cause severe damage to buildings. The level of damage varies from building to building, but can be generalized for the types of buildings common in Aizawl.

The scenario's duration of strong shaking is 10 seconds. "Strong shaking" is greater than 0.1g, the level at which landsliding is expected to begin. Figure 2 shows ground shaking, expressed in terms of peak ground acceleration, estimated using a simulation of the event by the United States Geological Survey using its ShakeMap software. Figure 3 was also produced using USGS ShakeMap software and shows the expected intensity of shaking from this scenario earthquake.

The computed level of shaking in the Aizawl area for the scenario earthquake would be described by people who feel it as "very strong" to "severe", and is assigned an intensity of VII to VIII on a scale with a maximum of XII. This intensity scale measures the strength of shaking from an earthquake in a particular place. People in neighboring states and in Bangladesh would feel weaker but perceptible shaking, as Figure 3 shows.

In every earthquake, the shaking varies somewhat from place to place, due to local soil conditions and other factors. Some areas would feel much stronger shaking, other areas lighter. For the purpose of analysis, however, this scenario considers a uniform level of ground shaking within the city. Though no studies have been done in Aizawl, evidence from past earthquakes elsewhere indicates that ridges and other topographic features can amplify ground shaking.

¹ Iyengar R.N. et al. (2010) *Development of Probabilistic Seismic Hazard Map of India*, Final Report to the National Disaster Management Authority, and MIRSAC (2005). *Hazard Risk and Vulnerability Analysis of Aizawl District*, Mizoram Remote Sensing Application Centre, Aizawl, Mizoram.

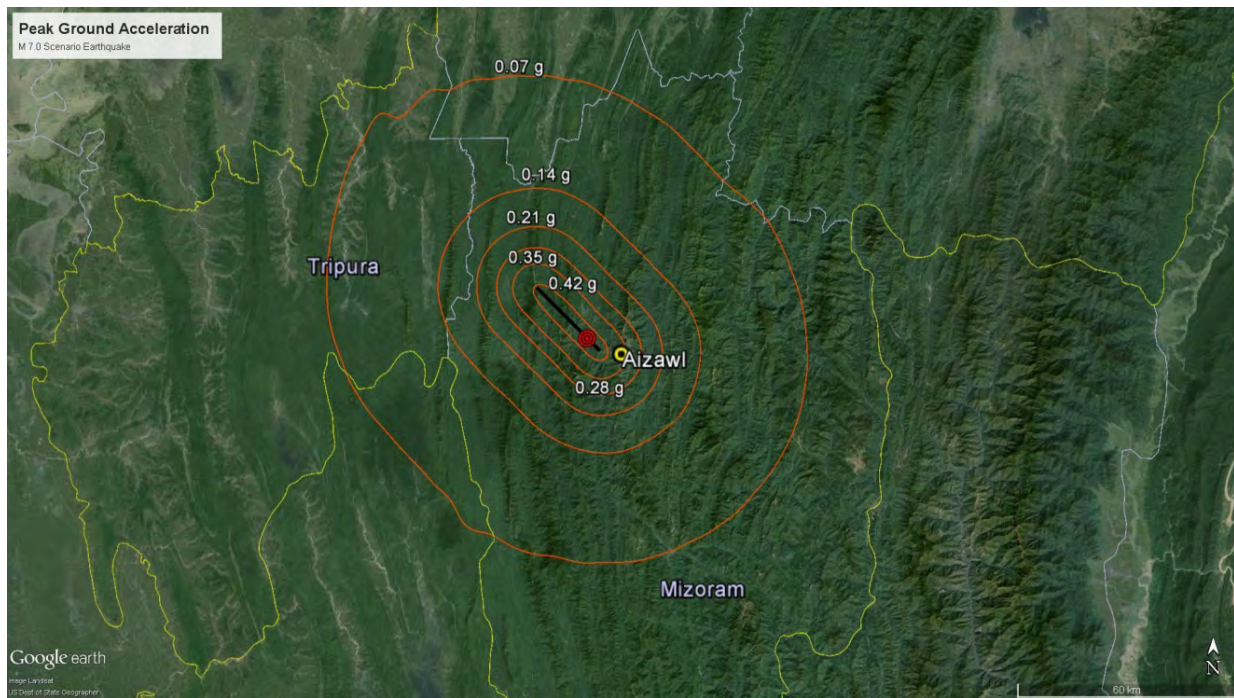


Figure 2. Peak ground acceleration (courtesy US Geological Survey)

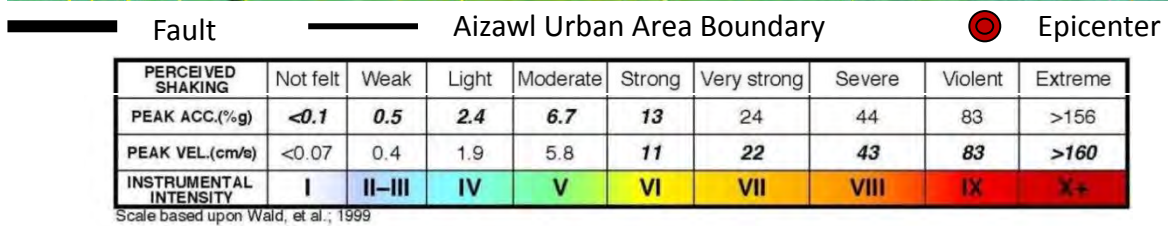
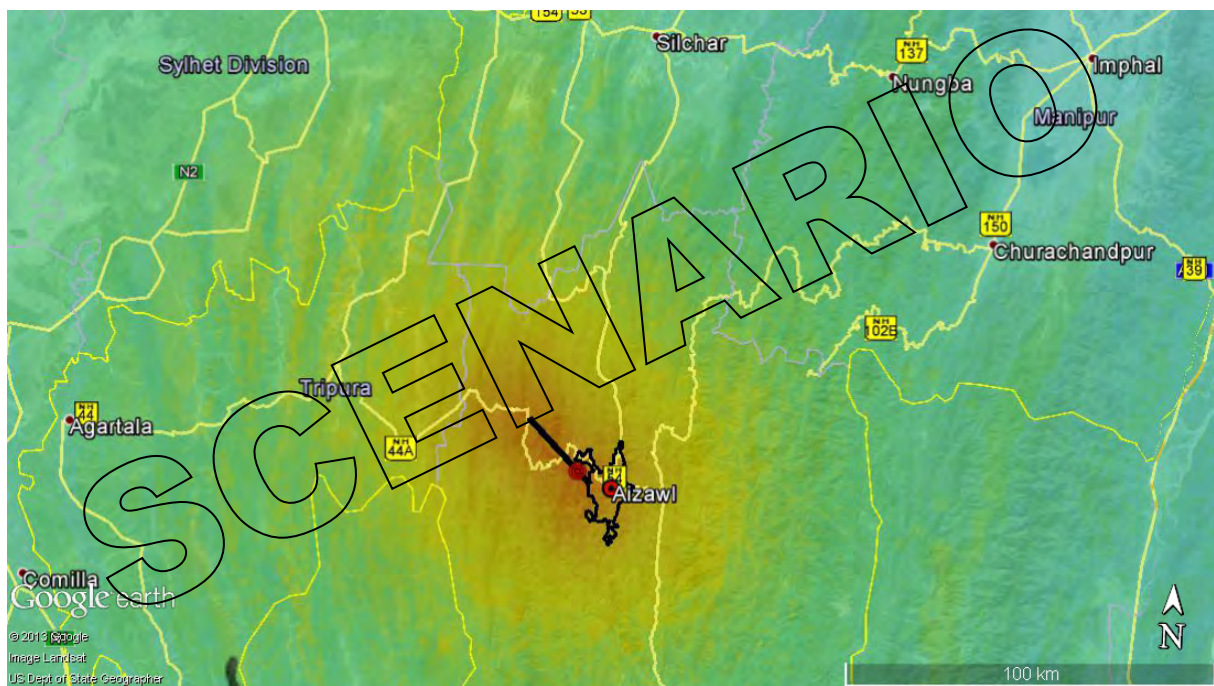


Figure 3. Shaking intensity (courtesy US Geological Survey) showing the regional extent of shaking; the event would be felt in neighboring states in India as well as in Bangladesh.

Hazards Triggered by Earthquakes

The shaking from the scenario earthquake causes several hundred landslides throughout the city and surrounding countryside. Fires start from various sources. Falling objects, both inside and outside of buildings, injure thousands of residents.

Earthquakes Trigger Landslides

Many new landslides occur in the scenario earthquake, especially on large areas of the eastern side of the main ridge, where landslide hazard is relatively higher because of bedrock geologic conditions. In addition to new landslides occurring, many existing landslides reactivate and move further down the slope. Rocks and large boulders tumble down steep cliffs.

The amount of movement as well as the size of landslides triggered by the scenario event will vary greatly between the dry season and the monsoon season, when slopes are saturated. More than 18 square kilometers of Aizawl's surface area will be affected during the monsoon season, compared to approximately 3.6 square kilometers during the dry season. Figure 4 shows landslide hazard zones for a portion of Aizawl; red and gold areas that make up approximately 88 percent of the mapped area show where more landsliding is likely to occur. In these areas, existing landslides are likely to move, and new landslides would occur. However, it is not possible to predict specific locations of the approximately 1100 landslides that we estimate the scenario event would trigger within the Aizawl urban area. Landslides triggered during the monsoon would be larger and more destructive.

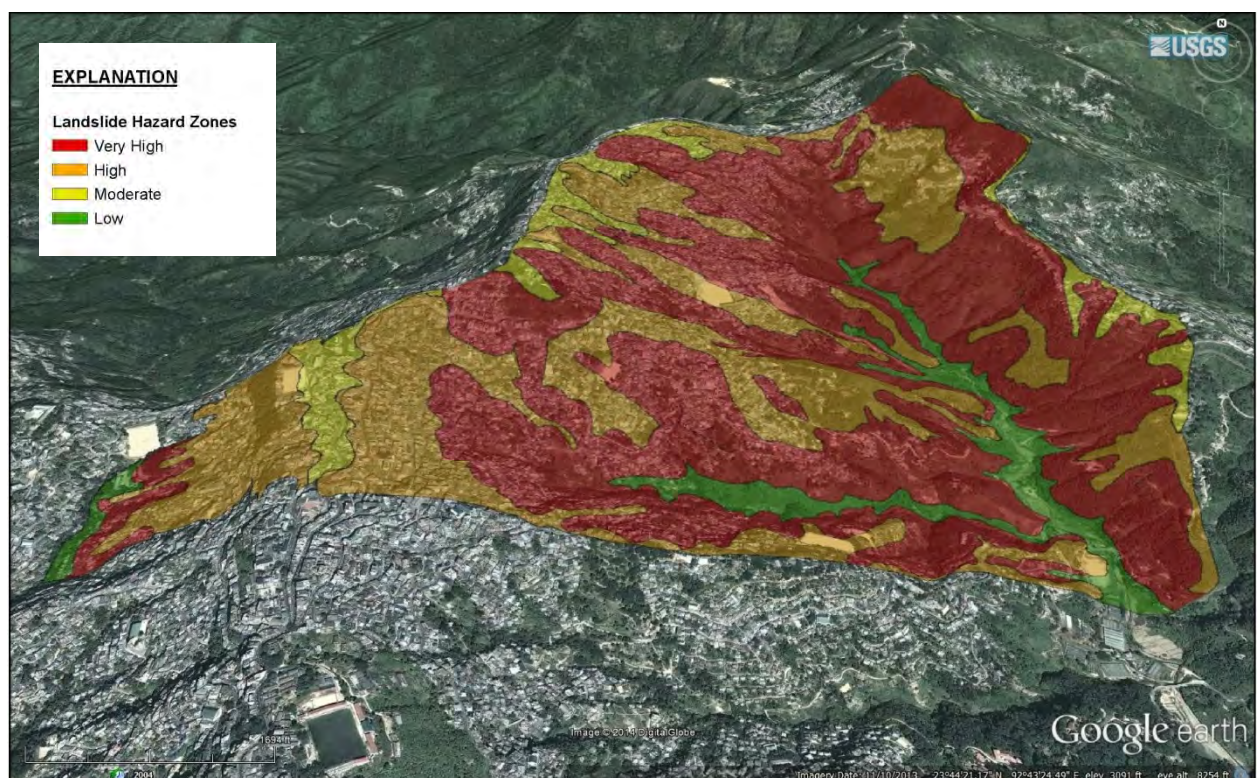


Figure 4. Landslide hazard zones for natural terrain in a portion of Aizawl; slope modifications made by people for building and road construction, quarrying, and similar activities may increase the hazard (Image credit: Lettis Consultants International)

If the earthquake occurs during the monsoon, 16 percent of the red areas and 9 percent of the gold areas are expected to slide. If the earthquake occurs during the dry season, 3 percent of the red areas and 2 percent of the gold areas are likely to slide. The landslide hazard zones in Figure 4 are for natural terrain, meaning the landscape without significant human modification. If people modify slopes without properly considering geologic conditions, and thereby reduce the slope stability as apparently happened in Laipuitlang (triggering the May 2013 landslide), the level of hazard may increase beyond what is shown on this map. [Appendix B: Landslides](#) contains larger and more detailed maps and figures describing Aizawl's landslide hazard, including a grayscale version for black and white printouts.

Aizawl is built on a ridge in which the rock layers (primarily sandstones and shales) are bent in the shape of an inverted “U”. The soil cover is generally thin, but the rock may be intrinsically incompetent (for example, shale is very weak) or may be compromised by weathering. The Aizawl area experiences three primary types of landslides, shown in Figure 5: translational rock slides, rotational rock slides, and rock falls.

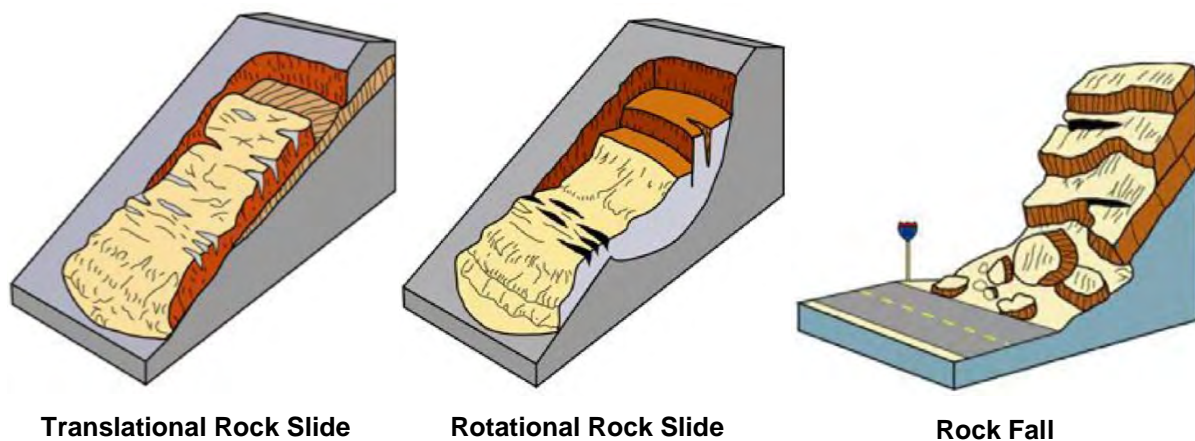


Figure 5. Common types of landslides in Aizawl (Image credit: Geology.com)

The May 11, 2013 Laipuitlang landslide that killed 17 people was a translational rock slide, meaning that the rock broke along a planar surface (visible in the center of the slide area in Figure 6). During the scenario earthquake, similar slides would occur on east-facing slopes with similar geologic conditions. In these locations, the rock layers dip in the same direction and at about the same angle as the slope, with weak layers of shale often hidden underneath stronger sandstone. In many places the shale is not strong enough to resist the scenario shaking, and the slope would fail in a translational rock slide.

A rotational rock slide has a failure surface that is curved instead of planar, as Figure 7 shows. The scenario earthquake would cause slides of this type as well.



Figure 6. May 11, 2013 translational rockslide in Laipuitlang (Photo credit: Lalrinpuii Tlau, GHI)



Figure 7. Rotational rockslide in south Aizawl (Photo credit: Kevin Clahan, Lettis Consultants International)

Rock falls, in which rocks detach from the slope and fall, roll or bounce down the slope, would occur in Aizawl's steep cliff areas. Loose rocks lying below slopes indicate previous rock falls, and are a sign that other rocks may fall. [Appendix B: Landslides](#) contains a detailed explanation of landslide hazards in Aizawl, as well as a description of the methods used to estimate the amount of landsliding during the earthquake.



Figure 8. Rock falls in steep cliff area in Aizawl (Photo credit: Kevin Clahan, Lettis Consultants International)

Earthquakes Ignite Fires

At the time of the earthquake, people may be boiling water for tea. Stoves tip and start fires. Pots fall and cause scalding. Following the earthquake, fires start from several sources.

The number and severity of fires depend on the time of day and weather conditions. Fires would be ignited by cooking stoves that tip over, gas leaks from cylinders, damaged electrical wiring, and heating equipment. Though fires occur in all building types, more fires start in buildings with wood floors and in collapsed buildings. The spreading of fire depends on building density, vegetation and wind conditions, so some fires spread to neighboring buildings and some do not. Under dry, warm and windy conditions, small fires can lead to a conflagration. In areas on the periphery of the city, some of the fires would spread into the nearby forest. If the earthquake occurs during the dry season, fires at the wildland-urban interface can threaten nearby localities.

Earthquakes Create Hazards from Falling Objects Inside and Outside of Buildings

Earthquake shaking causes damage to buildings and their contents, and this damage can harm people, increasing the number and severity of casualties. Buildings amplify shaking, so the accelerations near the top of some buildings could be more than twice as strong as at the base. This level of shaking is strong enough for thin masonry walls to crack and fall from buildings, and for furnishings, equipment and contents to slide or topple. Inside buildings, falling contents like cupboards and building elements such as brick infill walls endanger people, as do hot stoves, boiling water and cooking oil.

Outside, people face dangers from falling buildings or parts of the façade, including exterior architectural features, bricks used to infill between reinforced concrete columns, and water tanks. Downed, but still live, electrical wires can electrocute people. Moving vehicles threaten those who run into the street. After the earthquake, aftershocks dislodge bricks and pieces of concrete from damaged buildings, endangering anyone below.

Damage to the City of Aizawl

Building Damage Caused by Shaking and Landslides

Buildings in Aizawl suffer extensive damage due to the shaking that the scenario earthquake causes. We estimate that nearly 13,000 buildings collapse due to shaking alone—approximately 26 percent of Aizawl's approximately 50,000 buildings—and at least as many others suffer structural damage so severe that they are unsafe to use and must be demolished. Brick partitions inside buildings crack and topple. Thin brick walls in the upper stories of many concrete buildings fall onto the streets and pathways below, killing and injuring people outside of buildings. Landslides triggered by the scenario earthquake cause collapse of an additional 1200 buildings during the dry season, bringing total collapses to about 14,000, or 29% of buildings. Larger and more destructive landslides during the monsoon season collapse more than 6500 buildings, bringing total collapses to approximately 18,000, or 37% of buildings. (During the monsoon, some buildings that would otherwise collapse during shaking are collapsed by landslides.)

The dry season collapsed buildings include more than 18,000 housing units, and the monsoon season collapsed buildings include more than 23,000 housing units. In both the dry season and the monsoon season, at least as many housing units are badly damaged and uninhabitable as collapse, leaving more than half of Aizawl's residents without safe shelter.

In the hours and days following the earthquake, aftershocks endanger those who rescue victims trapped in badly damaged or collapsed buildings, because such buildings are unstable. The Civil Hospital is damaged, which impacts medical care for the community's emergency and long term needs.

Individual Building Damage Caused by Shaking

Most buildings provide housing and have been built by owners during the past fifty years. Aizawl's buildings consist of three major types: traditional timber (Assam-type; classified as Ordinary buildings by Aizawl Municipal Council AMC), concrete frame with lightweight walls and timber floors (classified as Semi-pucca or Semi-permanent buildings by AMC); and reinforced concrete frames, usually with brick infill and partition walls (classified as Permanent buildings by AMC). [Appendix C: Buildings](#) contains photographs and more detailed descriptions of the three building types. All three types of buildings are vulnerable to earthquake damage. Buildings constructed after 2007, when the Aizawl Development Authority (ADA) and AMC began to regulate building construction, are likely to be better designed and to survive the earthquake with less damage.

Buildings constructed on Aizawl's steep slopes are much more vulnerable to earthquake damage than buildings on flat ground. The short, stiff supports on the uphill side must resist large forces as the earthquake pushes the building out from the hill. Because these supports are short and stiff, they do not bend as easily as taller supports, and they must hold the building back by themselves rather than share the load with the taller supports. The long and flexible supports on the downhill side must move a long way as the building twists and sways. Both uphill and downhill supports can fail, and if either fails the buildings could collapse. This is particularly true of older buildings of all three types. However, even new, regulated buildings are more susceptible to damage when located on slopes.

Traditional timber Assam-type buildings are most vulnerable to damage in the under-building stilt supports, which tend to be poorly braced and have weak connections. Semi-pucca buildings often have weak, slender frames that may not be properly reinforced for earthquake resistance. Brick walls added later increase the weight and the danger. Reinforced concrete buildings have many vulnerabilities, but most fundamental is the lack of proper reinforcing for earthquake resistance. Improper reinforcing weakens buildings so they are unable to withstand the extra earthquake demands from hillside foundation configurations, open stories at road level, and large cantilevers used to increase room sizes in upper stories.

In many localities, buildings are closely spaced and can pound against one another as they shake. Heavy floor slabs in one building may repeatedly slam into the outermost columns in the adjacent building, breaking the columns and collapsing part or all of the neighboring building.

Appendix C: Buildings provides more information about building vulnerabilities and expected damage, and explains the methods used to estimate the number of building collapses and casualties.

Individual Building Damage Caused by Landslides

Landslides are often catastrophic to buildings caught in their path. Figure 6 shows debris from collapsed buildings that were atop the May 2013 Laipuitlang landslide. Buildings at the toe of the landslide were consequently buried by debris. During the scenario earthquake, we expect that all of the buildings directly and entirely atop landslides would collapse, as happened in the Laipuitlang landslide and in many other landslides in Aizawl. In densely built up areas, 50 percent more buildings would collapse from being crushed by landslide debris. A few slides might not fail catastrophically (and thus rapidly) during or immediately after the earthquake, but would likely move enough to badly damage buildings atop the slide and render them uninhabitable, or even cause them to eventually collapse.

Important Buildings

Hospitals, fire stations, government offices, schools, churches and Young Mizo Association halls provide essential community services. Most government buildings have been designed by trained engineers and built to Indian Standard codes by professional construction contractors, so they would have better earthquake performance, generally, than similar private buildings. Vulnerabilities of important buildings span a large range, from low-rise Assam-type schools constructed on flat ground (rather than stilts) that are expected to suffer minimal damage, to large older churches and institutional buildings that may suffer severe damage.

The Civil Hospital is likely to be damaged and would have a reduced capacity to treat patients. The main hospital building is likely to suffer damage that could make people inside question its safety. Interior damage to contents, brick partitions and building utilities system such as electrical power and water would disrupt operations. Damage to the hospital's other buildings could be worse. A landslide occurred on the slope below the hospital's west side in 2007. Further landsliding caused by earthquake shaking is possible and could threaten the hospital building if it occurs. Other hospitals would suffer similar structural damage and interior damage, disrupting their operations. Government buildings, YMA halls, and churches would suffer varying degrees of damage, according to their age and level of earthquake resistance. A number of older buildings would collapse.

Multiple-building Collapses

Steep slopes in densely built localities create a situation where vulnerable buildings are perched above other buildings, as Figure 9 shows. The configuration of many concrete buildings on steep slopes increases the chances that multiple floors of the building will fall downhill of the original building footprint during a collapse—crushing, damaging or collapsing the next building below.

During the scenario earthquake, we estimate that one-third of all building collapses would cause collapse of a building downhill. On a few steep slopes packed with vulnerable buildings, a collapse near the top would initiate a catastrophic cascading collapse that would destroy multiple buildings on the slope directly below.

Total Expected Damage to Buildings

Figure 10 shows the proportion of collapses by building type. The total of these collapsed buildings would represent 29 percent and 37 percent of all buildings in Aizawl, during the dry or monsoon season, respectively. Older reinforced concrete buildings would suffer the majority of the building collapses, with those on stepped sites faring the worst. Newer buildings designed and built to the AMC Building Regulations would be less likely to collapse due to shaking, though some buildings might still be affected by a landslide. It is clear that if owners insist that their buildings be built according to the AMC Building Regulations, they would greatly reduce their risk of being killed by a building collapse.



Figure 9. Vulnerable buildings on a steep slope where a collapse would endanger buildings below (Photo credit: Janise Rodgers, GHI)

During the dry season more than 18,000 units of housing would be lost due to collapse, and many more would be so badly damaged that they would be unsafe and need to be demolished. During the monsoon, more than 23,000 housing units would collapse. Assuming an average household size of 5 (Census of India, 2011), more than 90,000 people would lose their housing, if they survive the earthquake during the dry season. The number displaced by collapsed buildings would rise to more than 115,000 during the monsoon season. With the additional

people displaced from badly damaged buildings, more than half of Aizawl's population would lack safe shelter.

It is possible to greatly reduce these sobering numbers over time: by continuing, as AMC and ADA have done, to require earthquake resistant new buildings; by better enforcing the building regulations; and by putting policies in place that encourage and enable owners to strengthen older buildings.

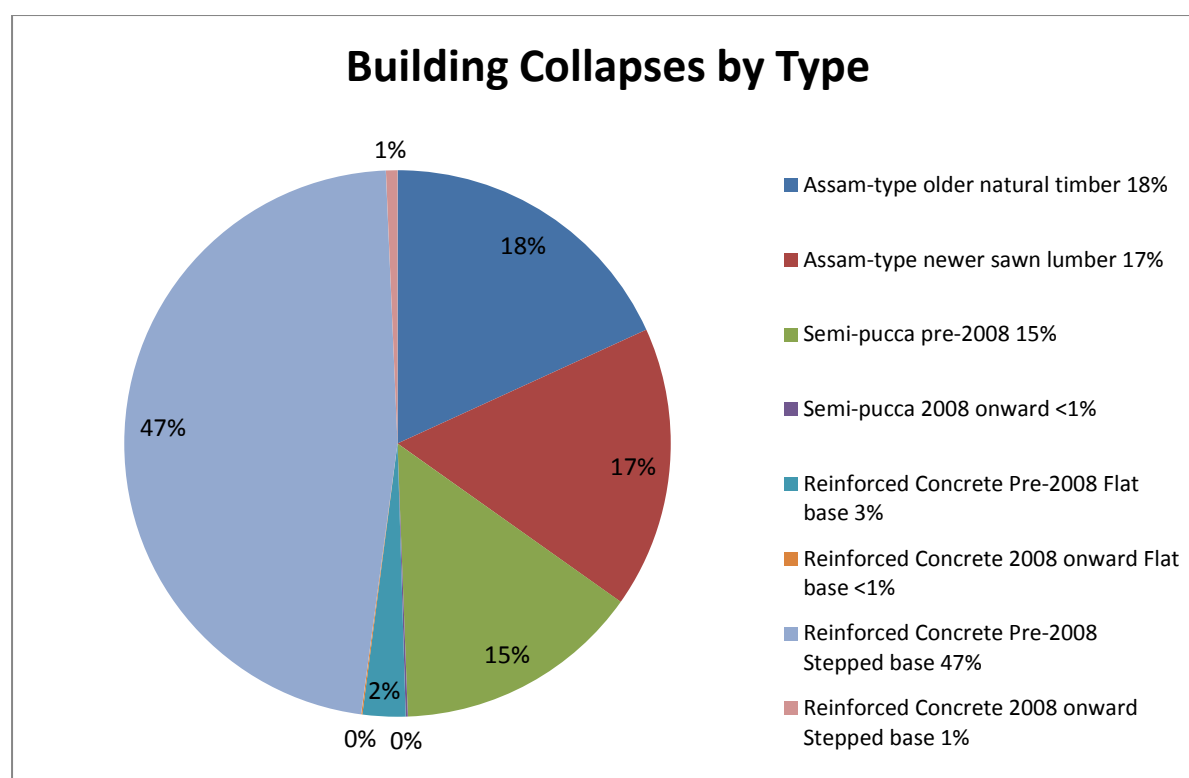


Figure 10. Proportion of the total collapsed buildings by building construction type and age for dry conditions; results are similar for monsoon conditions. Note that post-2008 buildings are assumed built to AMC Building Regulations; see Appendix C for subtype definitions.

Damage to, Utilities, Communications and Transportation Systems Caused by Shaking and Landslides

Damage to the electrical transmission system causes power to go out throughout Aizawl. Water lines broken by landslides and ground shaking leak precious water into the streets, and the damaged water supply system cannot provide more water to the city. In the immediate aftermath, residents do not fully comprehend that Aizawl is completely isolated. Communication options are severed. Landslides and building collapses block access roads. It may take days or weeks to bring in emergency water and power—and much longer to fully restore systems.

Water, electric, and communication systems and roads are the basic infrastructure systems that serve Aizawl's residents. They are called *lifelines* because people depend on them for life-sustaining services; this is especially true in Aizawl, where loss of transportation systems and clean water in particular are life-threatening.

Aizawl's water, electrical power, communications systems and roads are all vulnerable to earthquakes. When earthquakes strike, ground shaking can stretch and compress buried pipelines, conduits, and bridges, and can damage unsecured equipment. Landslides rip through pipelines, topple electrical poles, undermine and bury roads, and could block rivers. Bridge decks can be pulled off their abutments, and sandy saturated soils can liquefy and settle or move, damaging cables, pipelines, dams and equipment. Ground shaking and ground failure affect infrastructure, water mains, electrical transmission and distribution systems, and roads. This damage can be minimized by actions taken ahead of time to make pipelines, bridges and roads more robust.

Earthquake damage to infrastructure systems has consequences, which we discuss in this and later sections, measured in terms of the time needed to restore services, and the extent of repairs. [Appendix D: Infrastructure](#) contains technical information on how we determined consequences for the electrical power and water systems, as well as a description of each major infrastructure system.

Each of Aizawl's infrastructure systems depends on other systems. Water pumps rely on electricity; electric systems depend on roads for delivery of replacement equipment and workers. Emergency generators rely on lorries for fuel. Lorries depend on open roads. Communication systems—landline, cellular, mobile radio, Internet, broadcast radio and television and the print media—are needed to direct repairs and communicate emergency information. These systems rely on electric power, fuel for emergency generators, towers, lorries for supplies and buildings that house switches and controls.

Understanding the vulnerability of interdependent systems is necessary to improve their resilience and to provide life-sustaining aid following an earthquake. Each system relies on all of its elements. A single landslide can render the entire road useless, and loss of a single electrical transformer affects an entire distribution network. Systems depend on systems. Like chains, systems are as vulnerable as the weakest link. The interdependencies between systems, and their complexity, make post-earthquake restoration of service both urgent and intricate.

Aizawl is particularly affected by infrastructure damage from earthquakes for four reasons:

1. It is remote, and roads leading to it lack capacity and are subject to blockage by landslides and debris from collapsed buildings;
2. Many of its slopes are unstable during earthquake shaking, and the resulting landslides will damage utility systems, roads and streets;
3. Hillside construction is exceptionally vulnerable to damage from shaking, and collapsing buildings will damage electrical and communications systems and block streets; and
4. Its dense, urban population is uniquely dependent on infrastructure for food, water and medical care.

Investments can be made to make Aizawl much less vulnerable than it is today. The recommendations section that begins on page 39 of this document explains what can be done.

Water System

After the scenario earthquake, pipelines break in 50 or more locations due to transient movements in the ground and in about 50 locations due to landslides. A landslide could damage a pipeline between the treatment plants and the main reservoir. Damage to the treatment plants prevents the treatment of raw water that is critical to ensuring clean drinking water. Pumping stations and the associated electrical substations are damaged and out of service. Access for repairs stalls, because of road blockage within Aizawl and on the highways leading to other cities.

Emergency water supply is critical to survival for many weeks. The loss of the water supply leaves residents of Aizawl dependent on outside help to deliver potable water to distribution points for months. Because landslides, building damage, and traffic jam streets, most people and the supply lorries have difficulty reaching the delivery stations. Water is in short supply.

The municipal water system consists of two raw water intakes and treatment plants—Phase I and II of the Greater Aizawl Water Supply system—at Reiek Kai on the Tlawng River. Raw water is treated and then pumped 8 kilometers to the main reservoir at Tuikhuahtlang, about 1,100 meters above the treatment plant. A network of distribution mains supplies water to 29 zonal tanks throughout Aizawl. Homes and businesses maintain on-site storage tanks, supplied by periodic municipal deliveries, rainwater harvesting, and deliveries from private lorry tankers. The system is subject to earthquake damage and serious disruption in many ways.

The treatment structures and equipment can be damaged or dislodged by earthquake shaking, rendering them useless until repairs are made or replacements installed. The components comprising the electrical substations at the Phase I and II treatment plants and at the booster pump location are not currently anchored for earthquake motions.

Even if the pipelines remain intact, electric system failures, and failures at the treatment plant substations, would cripple the municipal water system. There would be no electricity to power pumps, chemical processes, flow controls and communications. Because the first set of raw water pumps are not connected to emergency generators or diesel pumps, the water supply is limited to the amount already in the system. The electric pumps that move treated potable water to the Tuikhuahtlang main reservoir through two separate pipelines are backed up by reserve pumps with diesel motors, but these diesel pumps can only pump a quarter of the total Phase II capacity. The stored diesel fuel varies from amounts that can last from a few days to three weeks. However, because diesel motors and fuel tanks are vulnerable to shaking damage if not anchored to resist earthquake forces, they would not be operable without repairs. However, chemicals needed to disinfect the water supply (salt and alum) are stored in ample amounts, so water treatment could resume as soon as any damage to the treatment equipment is repaired.

The treated water pipelines traverse a slope with active landslides. Distribution mains and local distribution lines cross numerous areas where landslides could occur or have occurred.

The two primary reservoir tanks at Tuikhuahtlang and the other major tank at Laipuitlang feed water mains linking sub tanks and distribution pipelines. Most of the tanks are reinforced concrete; the few steel tanks still in service are in the process of being replaced with reinforced concrete tanks. During the scenario earthquake, water would slosh against the tank walls causing the tanks to rock on their foundation. Tank walls can crack, but more often the tank movement will break their connection to pipes that lead to the distribution system. Broken connections and tank wall leaks can drain the tanks, causing localized flooding in addition to the

loss of precious water. Unless joints are designed to be flexible, water distribution systems are subject to failure both at the point where pipelines connect to the tank and along the distribution system.

Private lorry tankers deliver water mostly from perennial spring sources around the city. Lorries depend on passable roads and fuel. Depending on the water source, disinfection might be needed. Road access between the supply points and the urban area would be blocked by landslides.

Residential tanks generally are not anchored, and can slide and potentially fall from their supports during shaking. Falling tanks become a hazard to persons below, and water stored in them will leak out due to broken connections and damage to the tanks themselves. If anchored, these tanks could provide critical drinking water.

Wastewater

Landslides and debris blocks the system of street-side wastewater channels. Ground movement breaks drains, culverts and sewer pipes, and debris from collapsed buildings and landslides blocks them.

Interruption of the drainage system would divert waste and surface runoff from rainfall onto the streets, into low-lying areas and natural channels, and onto potential slides. Uncontrolled waste would contaminate drinking water supplies.

Electrical System

The electrical distribution system within Aizawl is damaged extensively. Repairs of transmission lines and major substations take several weeks, after which power could be delivered only to a few select customers.

Most of the power for Aizawl is generated outside the state and comes from the North East Grid by way of transmission lines from Jiribam, Manipur; Badarpur, Assam; and Kumarghat, Tripura. The Mizoram State Power and Electricity Department operates the electrical system. Power is distributed to 35 substations throughout Aizawl, which have equipment such as transformers, circuit breakers, and switches.

Substations would suffer extensive damage, and distribution circuits would suffer moderate to extensive damage. Extensive substation damage means that as many as 70 percent of the disconnect switches, transformers, circuit breakers are damaged. Given the expected damage rate, two 132/33 KV transformers would be dislodged, with one damaged beyond repair. Because the design of substation control buildings and transmission towers follows the Indian code for seismic provisions, these structures will experience less damage than other parts of the substation.

Key substation equipment, such as switches, circuit breakers and transformers, use brittle porcelain insulators, and transformers are supported on rails. Earthquake shaking would dislodge transformers from their rails, rendering them inoperable. Shaking forces would snap the brittle insulator stacks throughout the substation. Substation transformers that receive transmission voltages weigh from 16 to 18 metric tons, and special multi-wheel lorries and heavy cranes must transport and place them. Replacements might have to be transported from great distances over roads damaged by landslides and congested by vehicles serving other

critical recovery needs. Delivery could take up to one month and cannot occur until roads are cleared.

Hundreds of power poles would topple and break power lines. Transmission towers and poles supporting distribution lines pass through potential landslide areas. Individual towers might be damaged by slides and cause cascading failure of other towers. Re-energizing the distribution lines would take months; because it must be done zone by zone only after isolating damaged connections. If power is restored too hastily, there is a danger of energizing damaged lines, creating unsafe conditions and igniting fires.

The Zuangtui substation, a major substation where power is transformed from 132 KV to 33KV, would be damaged by movement of an existing landslide that underlies a portion of the station. Because work is underway to replace this substation with new facilities at Melriat, it would be easier to complete a new substation than repair the damaged one.

Damage to the electrical system would interrupt critical functions at hospitals, disrupt communication systems, and prevent pumping water from the Tlawng River. While many systems have backup batteries and emergency generators, these backups can be short-lived. These critical uses would require the use of backup generators for at least a month and regular delivery of fuel. However, unless properly installed to resist earthquake forces, backup generators, their switches and circuits, and their fuel supply systems can be damaged by shaking, so they will not function when needed most. Even when functioning, emergency fuel supplies are limited and quickly become dependent on fuel deliveries. Roads to Aizawl and within the urban area would be blocked for weeks while debris and slides are cleared.

Communications Systems

Earthquake damage to communications infrastructure, and the loss of electrical power, sever almost all of Aizawl's communications links to the rest of India and beyond. The Assam Rifles have the only functioning system that can be used to request outside assistance. Within the city, police, fire and traffic police radios are virtually the only functioning communication systems. With mobile and landline telephones, internet, television and radio all out of service for days to weeks, communicating within the city to coordinate relief efforts and reunite families becomes a major challenge.

Communications after an earthquake are essential to saving lives by directing emergency services, advising the affected population and coordinating repairs. These systems would be damaged and lose power. Systems that survive the earthquake on backup power would be overloaded and not operate effectively. Communications systems include landline and mobile telephone systems, broadcast radio and television, mobile radios, police and military satellite communication systems, satellite phones, internet and newspapers. (Appendix D: Infrastructure describes these systems in further detail). Most of these systems would be damaged from shaking and ground failure, and all depend on electricity. Backup battery life is limited. Some back up and emergency electric generators would operate but would quickly run out of fuel. Resupply would depend on fuel delivery. Solar power sources would continue to operate.

Landline Telephone Systems

Earthquake shaking, landslides and falling buildings would snap lines and topple poles. Damage to the control buildings, or internal damage, can topple backup battery racks and dislodge emergency generators needed for electrical power. Even without damage, congestion and open

circuits would jam telephone lines. If the system remains partially functional, system operators can use control switches to connect phones having emergency priority, but not others. Emergency generators have limited fuel supplies. Additional fuel supply for backup power would be critical for weeks.

Cellular Telephone Systems

A large number of cell towers and building-supported transmitter/repeaters would fail, reducing coverage and limiting system capacity. Backup batteries would be drained in hours. Large numbers of emergency generators or solar panels would be needed to restore minimal coverage, and to charge individual phones. The system would not function reliably during the immediate emergency period due to these failures and to call congestion. Call congestion would impede emergency communications and compromise system operations for months.

Mobile Radios

Emergency responders and public works officials rely on mobile radios for essential communications. These systems include radios, towers with receivers, transmitters and repeaters, microwave antennas and electricity. Personnel from the Police, Fire, Traffic Police, Public Health Engineering, Power and Electricity, and Public Works departments have radio systems. Initially, if the central receiving/transmitting equipment remains functional, these personnel could provide critical situation intelligence to decision makers and allow for some coordination.

Earthquake damage to antennas and loss of electrical power would limit the effectiveness and range of hand-held radio systems used by police, fire, electric and water department employees. For this scenario, the hand-held radios used by the traffic police, police, and fire employees would work, but other radio systems would not work. Communications between those conducting damage reconnaissance, directing repairs, coordinating resources would be compromised for at least one week, until adequate equipment is delivered and operating.

Radio systems are similar to cellular systems in that antennas are vulnerable to shaking damage, they need microwave antennas to align, and they need electricity to function. The central receiver/transmitter equipment needs to survive undamaged and have electrical power. Rechargeable hand-held radio batteries require electricity.

Satellite Phones

Satellite phones are not currently available to municipal and state authorities in Aizawl. Satellite phones are among the most reliable communication systems, because they do not rely on receivers and transmitters, on switching systems supported by towers and buildings, or on electricity to power the system. However, satellite phones are expensive to purchase and operate, so they are in limited supply. Satellite phones could be brought in after earthquakes for emergency use.

Satellite phones rely on batteries for power. Without reserve batteries and a charging system, the duration of use will be limited. In this scenario, no satellite phones would be available for two days until equipment is delivered.

Police and Military Satellite Communication Systems

Following the earthquake, these communication systems would be the only links to the rest of India. As such, they will be critical in the initial response phase to communicate the on-ground

situation and request outside help. POLNET, the satellite-based police data and voice communication system, would be a critical link as long as hardware is not damaged and backup power exists. The Assam Rifles in Aizawl, and at every one of their several outposts in various parts of Mizoram, have independent satellite based communications systems to contact the rest of the country. Each outpost has backup generators and stored fuel.

Broadcast Radio and Television

Radio and television are dependent on functioning equipment as well as power and a signal. Satellite dishes can be damaged by building and tower failures and knocked out of alignment. Television would not function following the scenario earthquake due to loss of power to individual sets. Cables from ZONET and LPS would be damaged by toppling poles and landslides. Also, televisions are likely to fall and break during shaking. Radios are more robust, and residents can even access radios in their cars and phones. Radios could serve as an effective communication system as long as transmitting facilities and radio sets have power. Mass communications are needed to provide vital directions and information to people. Without such official communications, misinformation and rumors can circulate.

Young Mizo Association Public Address Systems

In the scenario earthquake, some neighborhood systems would not function because of building damage and loss of power. The YMA maintains public address systems in many Aizawl neighborhoods. These systems provide a valuable resource for transmitting critical information. These systems also require electricity and functioning backup batteries or generators to work. Some neighborhood systems are linked—allowing for a single general message—but some are dispersed and independent. Receiving accurate information and messages from central authorities would be difficult.

Newspapers

In the scenario earthquake, we assume only one newspaper would remain viable. Newspaper production requires electricity for typesetting and printing. Because printing presses are in a building, the building must withstand shaking well enough to be occupied. Loss of the ability to print newspapers locally would mean that Aizawl officials would not have the ability to distribute information using existing resources. Distributing newspapers printed elsewhere would face the problem of road blockage and would be difficult for many weeks.

Internet

Internet connectivity is vulnerable to broken fiber optic cables and loss of electricity. Internet connectivity, except that which relies on satellite dishes (e.g., POLNET) would be lost. These systems require backup power, provided by generators, as well as stored fuel.

Transportation Systems

After an earthquake, roads would be the most critical lifeline, because the city depends on deliveries from the outside. Sustenance depends on delivery of food, water, fuel and emergency shelter; recovery depends on repair equipment and materials, and medical transportation.

Roads

In the scenario earthquake, road access to Aizawl, and circulation within Aizawl, would be lost. Multiple slides would sever the national highways and the road from Lengpui airport, requiring heavy equipment and construction of temporary bridges. Repairing slides and bridge damage to

establish even minimal access could take weeks, even with measures to speed repairs by allowing work at multiple locations, such as by transporting earthmoving equipment to intermediate points. Collapsed buildings with trapped victims would not be removed from streets until search and rescue operations are complete. Emergency vehicles, and lorries with critical equipment and supplies, would not be able to move within or through Aizawl for weeks. Search and rescue and life-saving medical care would be impeded. The Tlawng River bridge on the road to Lengpui could be damaged. A replacement bridge could be constructed within a few days as long as it could be delivered by helicopter.

Aizawl depends on two-lane roads for supplies and services needed for day-to-day survival. The most important roads are national highways linking Aizawl to the other cities, especially NH54 from Silchar, State of Assam. These roads traverse steep slopes where landslides frequently occur, blocking the way. These roads have several major bridges. The system of urban streets within Aizawl city is also critical to circulation of supplies and people. Aizawl's relatively few major urban roads and streets are narrow and congested on weekdays by automobiles, motorbikes, pedestrians, and parked vehicles. Circulation within Aizawl is vulnerable to landslides and blockage by collapsed buildings. Debris from damaged and collapsed buildings would smash cars and block streets, connecting walkways and stairs. It could take several weeks to open major urban roads and streets to allow lorry distribution of critical equipment and relief supplies brought in by helicopter. It would take much longer for street clearing operations to reach some areas of the city.

Airports

Lengpui Airport, located 32 kilometers from the city, connects Aizawl by air to the rest of India. Landslides would block the road connection between Lengpui, Aizawl and other damaged villages. The Tlawng River bridge between Aizawl city center and the airport could fail.

Strong ground shaking during the scenario earthquake would damage the terminal building. Even if damage does not jeopardize the safety of the building, occupants might evacuate the building after observing concrete spalling and cracking. The runway appears to be built on solid ground excavated from the ridge top and should survive strong shaking, except for differential settlement in any fill areas. Airport operations rely on the tower, communications, electricity, and emergency generators. Any runway damage could be repaired quickly with equipment and supplies available locally or brought in by helicopter. Fuel supplies needed to provide electricity for the landing system, lights and communications would be delivered by air.

Lengpui would serve as an important staging area and connection for receiving emergency resources and evacuating severely injured survivors. It would support incoming fixed wing aircraft as well as helicopters. Establishing communications capability, electrical supply and aviation fuel needed to support helicopter operations can be accomplished within a few days. Helicopters would be needed especially during the time the road to Aizawl is blocked. Transporting people, material and equipment from Lengpui to and from Aizawl by helicopter would be a logistical bottleneck until roads are repaired. The old airfield at Tuirial would be used as a staging area especially for helicopters delivering supplies and evacuating injured people. The Thuampui helipad in Aizawl would provide a location for helicopters to take off and land, as would other large open spaces in the city. Helicopters can also hover and winch down supplies in other areas.

Railroad

Aizawl is not served directly by rail. The nearest rail station is located at Bairabi, 120 kilometers to the north on NH 54 and NH 154. Bairabi is located beyond the area affected by strong shaking and should remain operational in the scenario earthquake. The rail system is vital for delivering heavy equipment, electrical transformers and construction materials to the region. Delivery of rail-borne supplies from the rail station to Aizawl depends on road conditions along NH 154, which could be compromised for weeks.

Fuel Delivery

Fuel supplies depend on regular deliveries from long distances. Deliveries rely on tankers and lorries driving from outside the city to depots and filling stations within Aizawl—and they require open roads.

Petrol and Diesel

Damage to roads and congestion would limit supplies severely for weeks. A lack of fuel would limit local generators' capacity to deliver electricity and would hamper repairs dependent on the generators and heavy equipment. Fuel for emergency generators and diesel pumps at the water treatment plant must be delivered by helicopter until access roads are reopened. Automobiles, lorries and equipment require petrol or diesel to operate, and backup generators require diesel. Fuel delivery depends on lorry tankers driving from Silchar to reach depot areas at Aizawl.

Cooking Gas

In the scenario, cooking gas supplies would diminish quickly because of road closures. The lack of gas to cook food and boil water would have health implications. Residents use liquefied petroleum gas (LPG) from individual high-pressure cylinders for cooking fuel. These cylinders are replenished at 25 filling stations throughout the city. The filling stations depend on bulk gas deliveries from lorries.

Consequences of Damage and Impacts on the Community

Human Casualties

The scenario earthquake kills approximately 25,000 people. During the monsoon season, the larger number of landslides and resulting building collapses increase the total number of fatalities to about 31,000 people. Certain building types and specific slope characteristics are more lethal than others.

Figures 11 and 12 break down the fatalities by cause. Building collapses due to shaking would cause the majority of deaths, and building collapses due to landslides and falling bricks would cause most of the remaining deaths. These numbers include 6400 people (nearly 8000 during the monsoon) who would die of serious injuries because they are unable to be rescued from collapsed buildings or cannot obtain medical care quickly enough. Figure 13 shows the fatalities caused by the collapse of each type of building. Older and poorly built reinforced concrete buildings are the main killers, both because more of them collapse and because these buildings are more lethal when they collapse. [Appendix C: Buildings](#) describes the methodology used to estimate the number of casualties. The number of people with injuries requiring hospital treatment is difficult to estimate, but generally ranges from between two to four times the number of immediate deaths. Life-threatening conditions would persist for weeks because of dangerous buildings, inadequate and contaminated water, lack of shelter, lack of medical treatment, and lack of food.

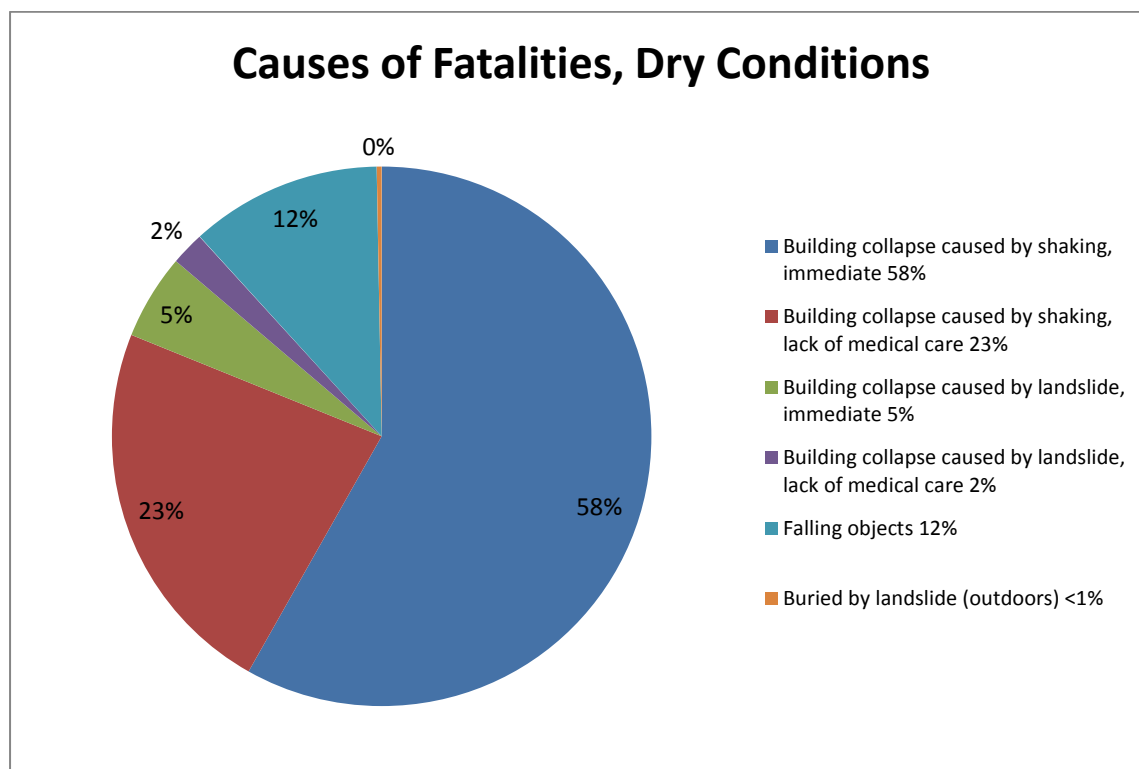


Figure 11. Causes of fatalities for dry conditions

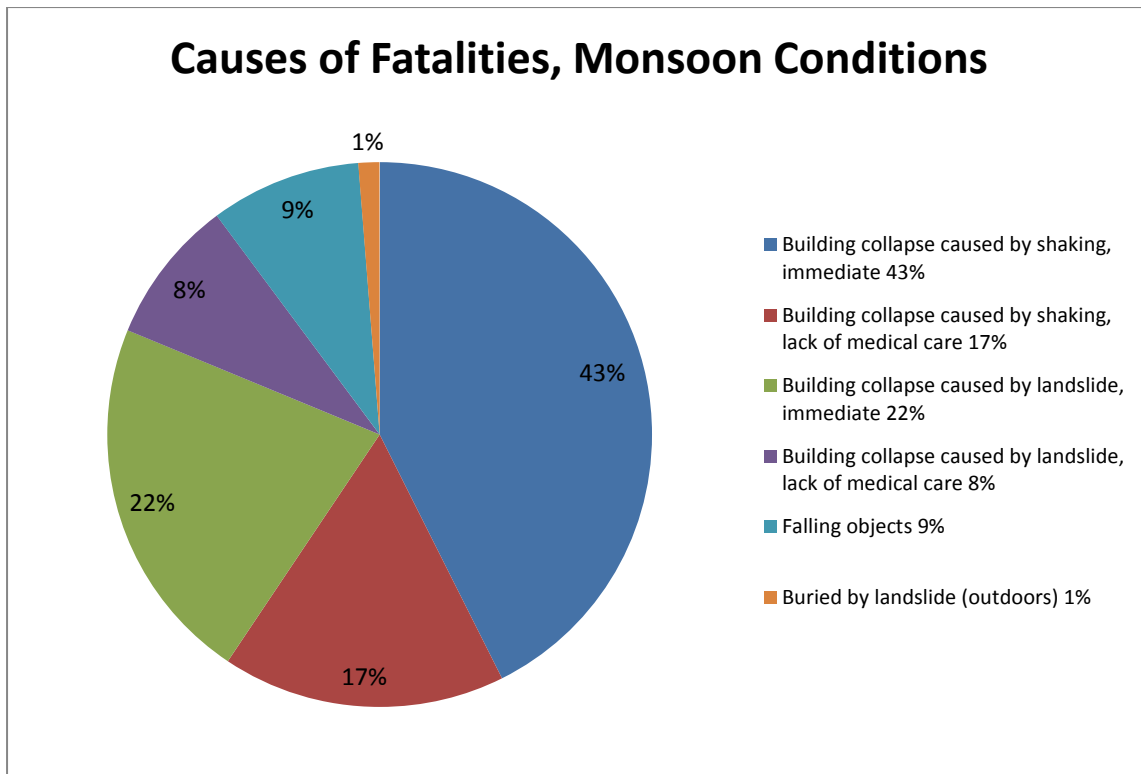


Figure 12. Causes of fatalities for monsoon conditions

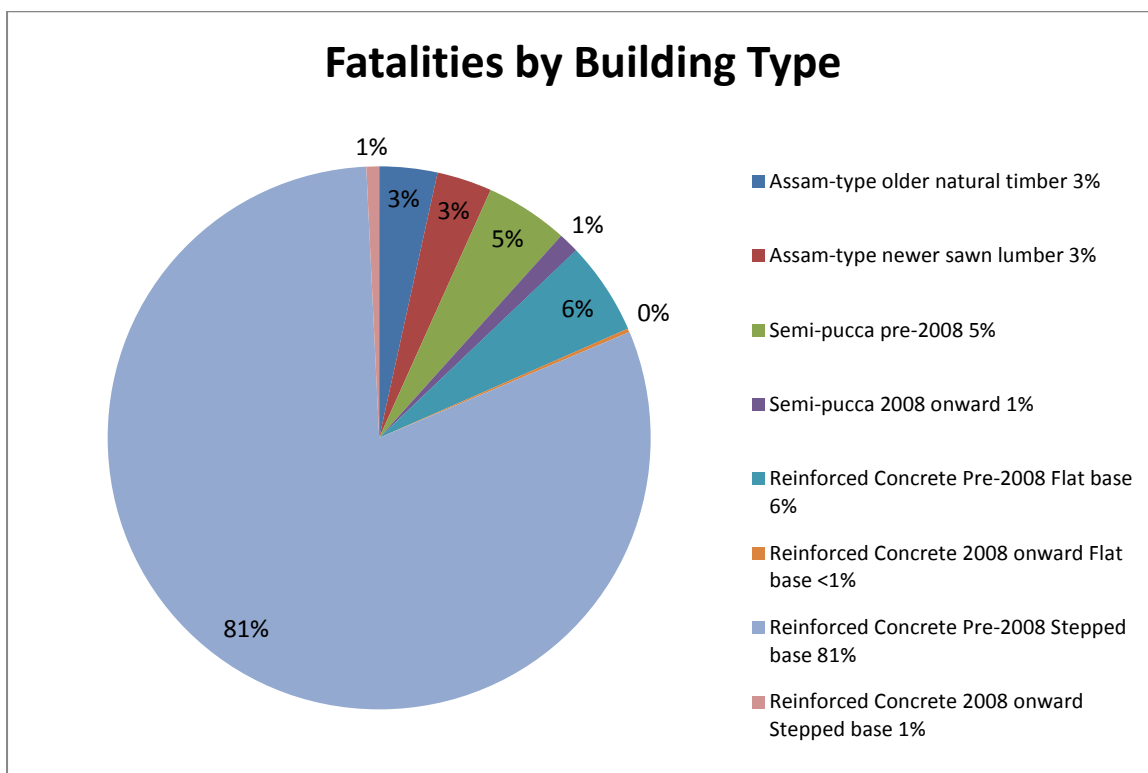


Figure 13. Fatalities due to building collapse presented by building type

Disruptions from Building Damage

Building damage, in addition to causing casualties, has immediate and severe impacts on the city's ability to function. Debris from collapsed buildings and fallen bricks block many of Aizawl's streets and pathways. Many survivors have no place to live. Destruction of shops, offices and commercial property causes people to lose their livelihoods. Market areas where people purchase food and basic necessities are destroyed or filled with debris. Hospitals suffer damage, and their backup power systems fail, leaving them unable to provide many essential medical services. Banks and ATMs are not functional, and few residents have cash on hand. Some government offices and staff quarters are badly damaged or collapsed, disrupting government services. About 14,000 collapsed buildings and many badly damaged buildings must be replaced.

Determining which buildings are safe to occupy based both on structural damage and slope stability, and deciding which can be shored and/or repaired are public safety decisions with life-threatening implications. These decisions can be difficult and require time spent by trained engineers to assess the damage and design repairs. Owners of buildings that collapse or must be demolished would lose everything saved and invested for decades. Replacing this large number of buildings would take decades and would proceed slowly given financing limitations, limited transportation infrastructure, limited work space, and a lack of skilled workers, materials, engineering expertise, and government regulators. The number of buildings lost to collapse or irreparable damage represents many decades of construction. Aizawl—indeed, Mizoram—would be changed forever.

Utility Breaks and Interruptions

Broken water pipes quickly drain water from Aizawl's zonal tanks and distribution system. Residents whose household water tanks have not fallen from supports have water for up to a week, but the tanks soon run dry. With the water system out of service, the water shortage becomes acute. Some people trek downhill to the river and streams to fetch water, but springs, wells and river sources have been contaminated. Without treatment, water from these sources could lead to the outbreak of disease. The loss of water impedes fighting the fires ignited by earthquake shaking and building failures. Loss of electrical power also disrupts critical public services and hinders response efforts. Backup generators, and the fuel to keep them running, become critical for the round-the-clock response effort.

People would begin searching for water wherever they can during the dry season, obtaining water from questionable or polluted sources. Waterborne disease can spread this way. During the monsoon, people would harvest rainwater, so the shortage would not be as acute.

Disruption to Critical Medical Care

Hospitals lack water for drinking or for sanitation and sterilization. The loss of transportation links prevents re-supply of critical medicines, medical supplies, medical gases and fuel for generators. Key equipment is damaged; the staff does the best they can, but it is almost impossible to treat the tens of thousands of badly injured with no water, no power, no sterilized instruments, and scarce supplies.

Aizawl Civil Hospital, along with several smaller private hospitals including the Presbyterian Hospital in Durtlang, provides critical medical services for Aizawl residents. The recently opened State Referral Hospital in Falkawn is far from the main populated areas and is currently lightly used. Earthquake damage in hospitals, and to the transportation networks that access

them, can interrupt medical care delivery in several ways. Structural damage to the building or slope instability can compromise the facility's safety. Interior damage to equipment, contents and the architectural finishes such as suspended ceilings and partitions can render the hospital unusable. Loss of electrical power, water and communications can cripple important hospital functions. Blocked roads and paths would make it difficult for patients, relief supplies and additional medical workers to access any of the hospitals, and would make it difficult to transfer out severely injured patients. The Presbyterian Hospital in Durtlang and the State Referral Hospital in Falkawn would be cut off from the rest of the city by landslides and collapsed buildings that block the road.

A Local Example of Earthquake Impacts: Case Study of Electric Veng Locality

To provide an example of the scenario earthquake's consequences and impacts on a more local level, we estimate the potential impacts on one of Aizawl's 92 localities (local council areas), Electric Veng. Many localities in Aizawl share at least some similarities with Electric Veng and might experience some similar impacts. Situated on the east side of the main ridge, Electric Veng is in the central portion of Aizawl. Its slopes are densely packed with many commercial buildings in addition to residences. Figure 14 shows most of the locality, viewed from the east.



Figure 14. Electric Veng, viewed from east (Photo credit: Janise Rodgers, GHI)

According to the Aizawl Municipal Council's 2009 houselist survey, Electric Veng has approximately 450 buildings and more than 1220 households. Assuming Aizawl's average household size of five people, the estimated residential population is about 6100 people. Buildings are mostly reinforced concrete, built prior to the introduction of building regulations in 2007, and Assam-type. Our field inventory shows that buildings are approximately 63% reinforced concrete (57% older buildings with stepped bases, 1% newer buildings with stepped bases, 4% older buildings with flat bases, 1% newer buildings with flat bases), 32% Assam type (10% older and 22% newer), and 5% semi-pucca (4% older, 1% newer).

Important buildings in Electric Veng include the YMA Hall, the Mizoram Power and Electricity Department headquarters, and several large churches. The locality has an electric substation but does not have a zonal water tank. Like most localities on the ridge's sides, Electric Veng has a number of streets running north-south, parallel to the ridge line. No streets run east-west (up and down the hill), meaning that travel uphill or downhill must be on foot via numerous stairs, or by traveling a north-south road to the end of the locality or beyond and back again.

Electric Veng sits almost entirely on an east-facing slope, which is approximately parallel to the bedding planes of the rock formation below, making the slope particularly susceptible to

landslides. As a result, the entire locality is either in the zone of high landslide hazard (62% of the locality area) or very high landslide hazard (38% of the locality area) as defined in Figure 5 of [Appendix B: Landslides](#). These zones represent hazard in undisturbed, natural terrain; human modifications to the slopes, such as cutting the slope to build roads or buildings, may increase the hazard further. Figure 15 shows the approximate Electric Veng boundary (in blue), locations of important buildings and roads, and the landslide hazard zones.

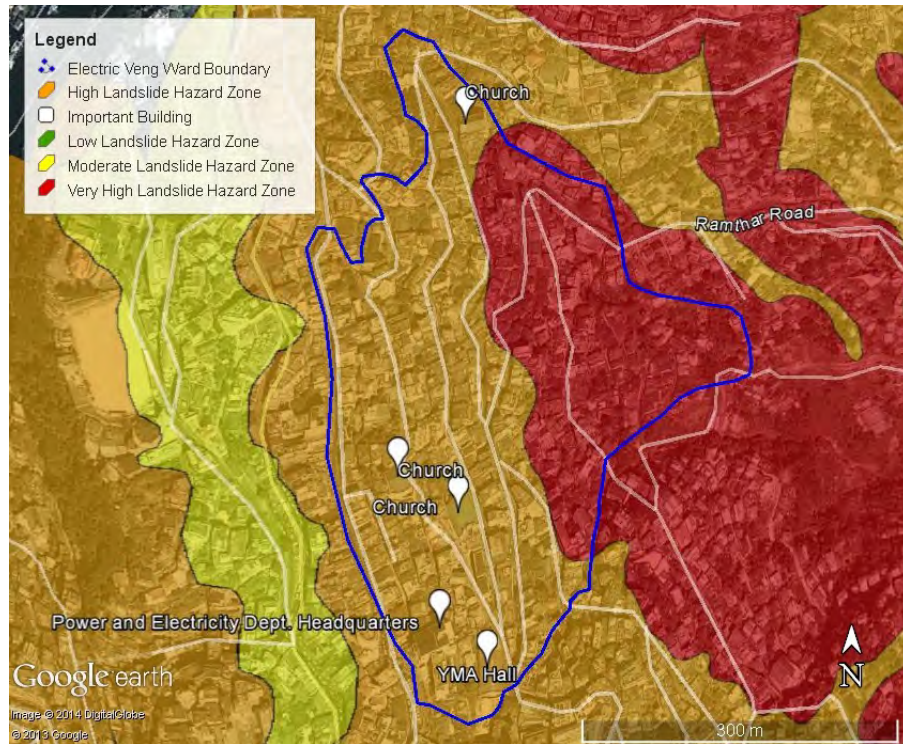


Figure 15. Electric Veng (boundary in blue) with landslide hazard zones, roads and important buildings

If the scenario event occurs during the dry season, 3 percent of the red area and 2 percent of the gold area in Electric Veng (shown in Figure 15) is expected to slide. The resulting landslides would collapse approximately 10 buildings during the dry season and 60 during the monsoon; shaking alone would collapse another 110 buildings during the dry season and 100 buildings during the monsoon. (Shaking collapses fewer buildings during the monsoon, because buildings that would otherwise collapse during shaking are collapsed by landslides instead.) In the dry season, more than 25 percent of Electric Veng's buildings would collapse; during the monsoon more than 35 percent could fail. During the dry season, these collapses along with falling bricks would kill approximately 500 people immediately; another 150 people could die from lack of medical care, bringing total deaths to more than 650—more than a tenth of the locality's residential population. During the monsoon, 650 people would die immediately, and another 200 would die from lack of medical care, bringing the total deaths to more than 850. The power would go out due to damage to the substation. Numerous water distribution lines would break, and household water tanks would topple and break their connections. Debris from collapsed buildings would block roads and stairs, trapping people in the neighborhood and impeding access for rescuers.

In addition, the occurrence of a large, catastrophic landslide during the strong shaking produced by the scenario earthquake cannot be ruled out. Large landslides, such as the 1992 Hlmen

Quarry landslide, are known to occur in the Aizawl area. In northeast Aizawl, we found geomorphological evidence of a number of large landslide complexes (see Figure 2 of [Appendix B: Landslides](#)), indicating that large landslides occurred prior to Aizawl's written history. These pre-historic landslides may have initiated from extreme monsoon rainfall events or as the result of strong ground shaking.

For illustration purposes, we examine what might happen if a catastrophic landslide were to occur in Electric Veng. Other localities with similarly adverse geologic conditions could possibly experience a catastrophic landslide; it is **not** more likely to occur in Electric Veng. Both the Hlmen quarry landslide and the much smaller May 2013 Laipuitlang landslide occurred in areas with similar geology to that underlying Electric Veng. Furthermore, slope stability calculations carried out for a cross section through Electric Veng (shown in Figure 4 of [Appendix B: Landslides](#)) indicate that a large landslide could occur at 0.35 g shaking under both dry and monsoon conditions, and at a much lower level of shaking (0.1g) during the monsoon.

Figure 16 shows the devastating effects that a large landslide would have on Electric Veng. In this example we have drawn a landslide of the size our slope stability calculations indicate is possible in a hypothetical but reasonable location in Electric Veng. Fortunately, a landslide in this location would not collapse any important community buildings, but two large churches would sit near the head scarp and could be at risk from subsequent landsliding. This hypothetical landslide would sever all but one of the locality's north-south roads, impeding travel. The landslide would collapse approximately 80 buildings. These collapses would kill a number of additional people not included in the overall total for Electric Veng mentioned above. We assume that the total fatalities caused by the scenario earthquake remains unchanged, because the method used to estimate the total area of landsliding (and its consequences) uses an average percentage of landsliding over the entire city. We assume that concentrated damage from larger landslides, which cannot be ruled out, is offset by fewer landslides elsewhere.

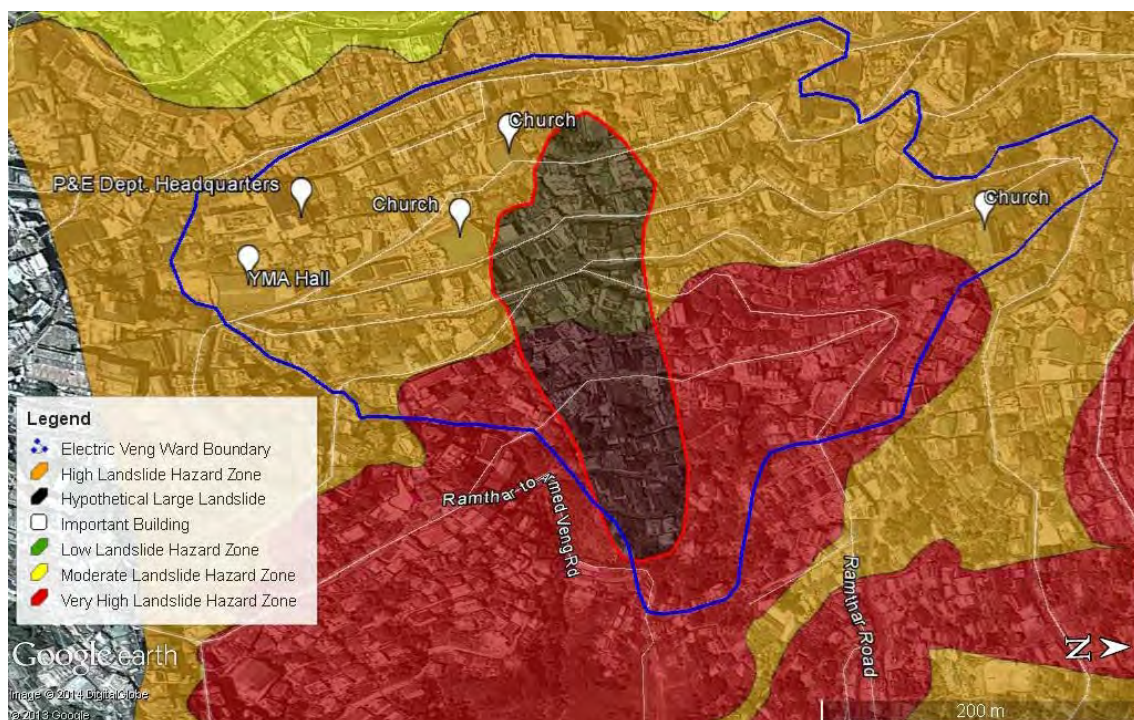


Figure 16. Hypothetical large landslide superimposed on Electric Veng

Emergency Response and Recovery

Emergency Response following the Scenario Earthquake

Earthquakes, like other rapid onset hazard events, are initially dramatic and frightening, but in reality the danger extends for some time. Aftershocks that damage or destroy buildings and infrastructure continue for weeks, or perhaps months. Both the main shock and aftershocks trigger landslides and fires. The consequences evolve and the number of casualties grows. Neighbors, first responders from the community, and state and national government responders carry out rescues, provide medical treatment, transport those needing higher level medical care, and provide the food, water, medicine and shelter needed to sustain victims until early recovery begins. In Aizawl, response is made much more challenging by geographic isolation and the lack of access due to blocked roads and streets. Also, the very dense urban environment has few flat open spaces in which to stage relief and shelter survivors, as Figure 17 shows.

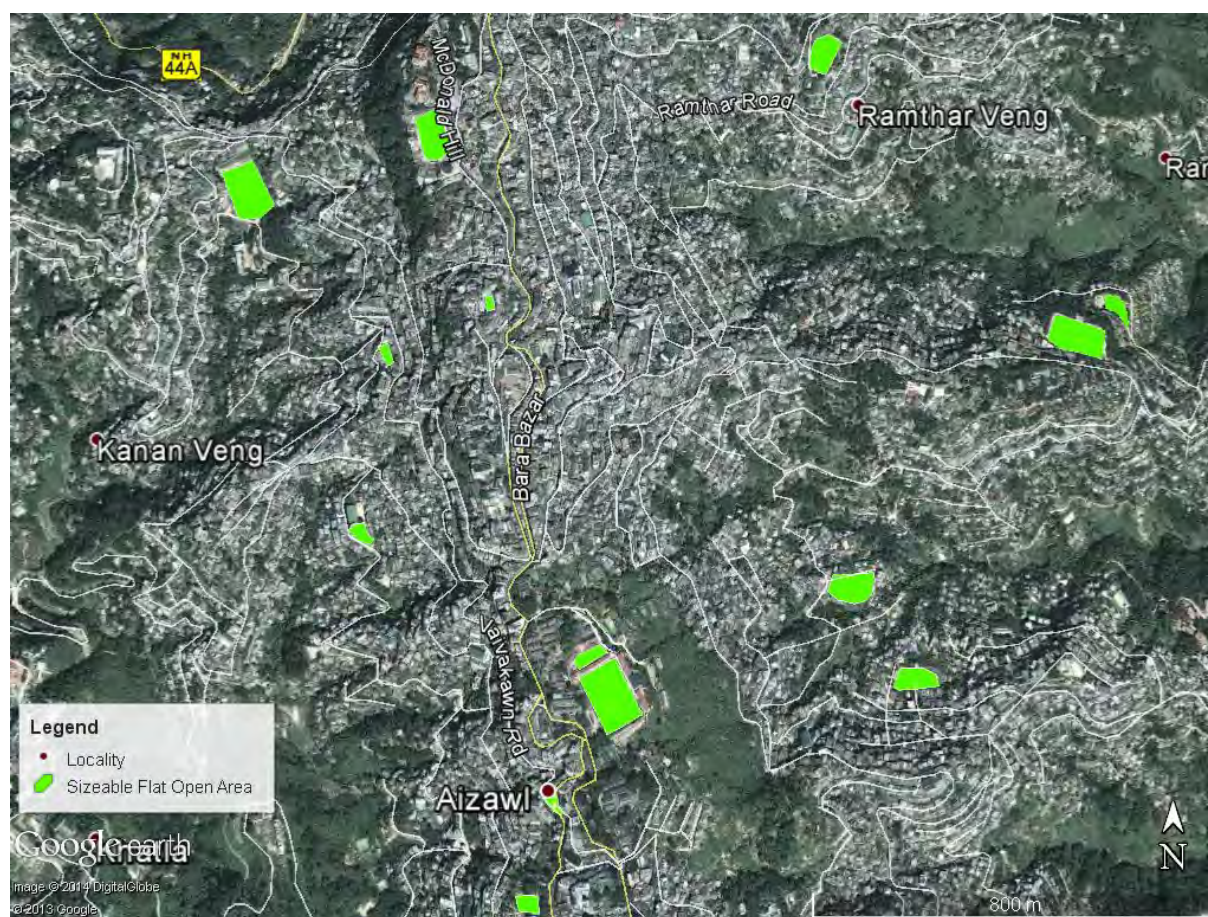


Figure 17. Sizeable flat open spaces in the central part of Aizawl city (in green)

This section provides a situation report-style description of the emergency response activities that would take place following the scenario earthquake. Organized using a timeline, it is intended to highlight issues and problems that emergency/disaster managers would face at different times during the response and early recovery period. Understanding these issues will help emergency managers improve plans, increase coordination between agencies, and bolster response capacity. Such improvements are feasible in the near-to-medium term, and can be cost effective when integrated into ongoing planning processes and preparedness programs.

Day One

The city is rocked by the 7.0 magnitude earthquake at 2:00 PM. A large dust cloud created by collapsed buildings rises over the city. The response begins almost as soon as the shaking stops. Initial reports of the event are shared with the Government of India by the Assam Rifles via their military communications network, which is the only functioning communications link between Aizawl and the rest of India; all other communication links are out of service.

The staff in the Disaster Management and Rehabilitation Department (DM&R) activates the State Disaster Management Committee (SDMC), and the staff in the office of the Deputy Commissioner (DC) similarly activates the City Disaster Management Committee (CDMC). There is damage in both the DM&R and DC's office buildings, and all communication systems are down. Some members of the staffs and state and city disaster management committees are unaccounted for. Members of both committees are spread across Aizawl when the earthquake strikes, and with roads blocked and all telephone service down, there is no way to quickly determine whether the members have been injured or have even survived, and who will be in charge of the response effort. Without communications capability and the ability to move quickly within the city, the SDMC and CDMC have no way to quickly assess the extent of the damage, which areas have been hardest hit, and how many people may have been injured or killed. They are unable to meet in person. Nonetheless, it is clear this is a major disaster and the State Government declares an emergency. In the localities, Locality Disaster Management Committees (LDMCs) are activated by whichever members happen to be present in the locality at the time of the earthquake. They are able to obtain information more quickly, but streets and pathways blocked with debris make it difficult to move within localities. They must communicate through direct conversation.

With no other way to communicate and no knowledge of how the Assam Rifles were affected, DM&R sends a staff member on foot to the nearby Assam Rifles headquarters in central Aizawl to ask them to use their communications systems to contact the Ministry of Home Affairs (MHA) and NDMA and to request deployment of National Disaster Response Force (NDRF) teams. The SDMC sends a runner to contact and coordinate with the CDMC. The Emergency Operations Center (EOC) in the DC's office would be activated, but because of substantial damage to the DC's office compound, a temporary EOC is established nearby.

The Incident Commander (DC or person in-charge in the DC's absence) and the EOC immediately send runners to all line departments and LDMCs to give and get information. With landline and mobile phones out of service, and other wireless radio systems not functioning due to the loss of power and inadequate backup, the only functioning local government communications system is the wireless police radio. Where communication is not possible, (such as with LDMCs), messengers are sent, but travel is slow, on foot and dangerous. Every member of the teams sending and receiving messages is at that moment also concerned about the safety of family members who may be in different parts of the city at the time of the earthquake.

At sites of collapsed buildings, the survivors and neighbors pull as many people from the debris as they can, but these community members do not have heavy equipment or training and cannot free a number of people trapped by heavy concrete slabs. Local YMA branches begin to organize groups of searchers in each locality, but these teams do not have heavy equipment. Survivability in earthquake-collapsed buildings in the first hour is 90%, but then it drops rapidly. The

number of severely injured needing immediate medical care for crushing injuries, for broken bones and arterial bleeding is not known. Neighbors, family and local YMA teams will rescue the most people, simply because they are nearby and can respond immediately. Some of these informal rescuers take risks going into damaged and collapsed buildings, and some are injured and killed by further collapse and shifting of debris caused by aftershocks.

Professional rescuers, such as the State Disaster Response Force (SDRF) units, also begin rescue efforts, but they are too few in number, given that there are over 14,000 collapsed buildings and they are hampered by communications and travel difficulties. SDRF units are attached to three Mizoram Police battalions in Aizawl, so the surviving members of these teams were within their own battalions executing normal duties when the earthquake struck; they must regroup at the pre-appointed place before deployment. It takes them hours to assemble, and many members are missing, either because they cannot travel to the appointed site or because they are helping to rescue people in the location where they were at the time of the earthquake. The first members to arrive begin searching nearby buildings, but there are so many collapses that it is clear the number of SDRF search teams is completely inadequate. Roads are blocked by fallen buildings, so these teams move on foot. They must carry electrical generators to operate search and rescue equipment at building collapse sites. Progress is slow, with entreaties from neighbors and family members to search each of the many collapsed buildings along their route. Teams may be redeployed when news arrives of many people trapped by collapses of large buildings. Deciding which buildings to search is controversial—and emotional—because survivors call out for help at thousands of locations. The task at hand is overwhelming.

Assam Rifles teams swing into action as well, despite some damage to their own buildings and loss of equipment. In addition to helping search damaged buildings, they help maintain order and begin the daunting task of trying to clear roads of debris. As more news comes in of localities affected by earthquake-triggered landslides, the SDRF teams are further deployed with assistance from untrained police personnel and local YMA teams.

Friends and family immediately bring people with minor and major injuries to all of the hospitals. Each hospital activates its response plan and makes arrangements to receive many times their normal daily handling capacity. The number of victims overwhelms the facilities and staffs. Most hospital buildings are damaged, so in-patients and earthquake victims are treated in the few nearby open areas. Many people have suffered heart attacks. Hospital staff must use triage to separate those who need immediate treatment from those who do not, and to determine which of the badly injured are beyond saving. These are difficult decisions complicated by the fact that families find many decisions and priorities hard to accept. Crowd control and security are needed. A few injured staff members and in-patients are evacuated and treated. The skeleton security staff available at the hospitals tries to control crowds. Everyone wants his or her loved one treated immediately. Hospitals use Public Address systems to give out information. Staff members are worried as news—and rumors—comes in of some collapses in staff quarters and damages to school buildings, but they bravely continue treating the injured.

Schools activate their disaster management plans and evacuate children to safe locations. Some children and staff were injured by damage to buildings and falling contents. Many schools located in rented buildings have suffered damage and casualties. Many schools have lost their 'safe' evacuation locations due to collapse of other buildings around them; teachers and students have to assemble in different, possibly unsafe locations. Many teachers rush home to

look after elderly parents and infants left with family members or domestic help. School children are traumatized by the losses in their schools and the injuries around them. School search and rescue, trauma counseling, and first aid teams formed as part of the disaster management plan are overwhelmed by the number of children requiring assistance. Some children attempt to walk home on their own, but they are discouraged by alert teachers. Most schools have not involved parents in their mock drills and do not have arrangements in place for releasing children to their parents or other relatives.

In the 92 Aizawl localities, many of the response team members or their families are victims. Many families have been separated by the event, and surviving members are worried about the safety of their loved ones. The local search and rescue teams organized by YMA swing into action and begin searching collapsed buildings for survivors. Some of their equipment is lost in collapsed structures, but the teams manage with whatever they can get. Members of local first aid teams, who are not injured and who are in their own locality when the earthquake strikes, begin to provide first aid for injured survivors after checking on their families. Some members of these teams join with the local search and rescue teams. No rescues are painless; there is immediate need for specialist medical attention that local first aid teams are not able to provide. They send team members to the DC's office to inform of the grim situation and request for deployment of SDRF teams. Some downed power lines are still live, and community members try to turn off electricity on their own. Some people report LPG leaks from under collapsed structures and warn people not to light cigarettes, fearing a fire or explosion. The sounds are unnerving. Damaged buildings creak and groan during aftershocks and as landslides continue to move. Sirens from emergency vehicles wail. Terrified dogs bark outside collapsed structures, probably looking for lost people. Dust causes respiratory problems for many persons, especially the elderly.

Some seriously injured persons extricated by the search and rescue team are given first aid and carried to the nearby hospitals in makeshift stretchers. Some women in an advanced state of pregnancy are assisted to nearby hospitals by members of the first aid team. Many ask for water, but the teams tasked with preparing food are not able to provide water due to damage to the water system.

Fires break out and are fought by residents using water, sand buckets, etc. However, broken water lines and toppled residential water tanks decimate water supplies.

LDMC information dissemination and damage assessment teams in localities close to the DC's office send runners to provide initial estimates of the number of casualties and building damages, and to ask for help and facilities to store dead bodies. In localities far from the DC's office, the LDMC members quickly realize that travel to the DC's office on foot will not be possible before night falls, and too dangerous in the dark, so they search for police with functioning radios, their only other means of communicating with those coordinating the response.

Churches are designated safe shelters for victims, but many church buildings are badly damaged. The community converges at churches that appear to have only slight damage, offering to help in whatever way they can. Many come seeking prayer as well as the comfort and support of their church family. Shelter management team members, helped by volunteers, try to arrange lighting before night falls, so that search and rescue efforts can continue.

Most generators have less than a few hours of fuel backup and will cease to operate during the night. Very few petrol pumps can operate or have functional generators, and access is limited by building collapses and landslides. The generators of the SDRF teams are running out of fuel and need to be replenished immediately. Some generators are heating up due to continuous usage. Radio handset batteries are running low, and where generator backup is not available, these stand the risk of running out. Teams from telephone service provider BSNL are trying to get their systems to work again with limited success. A strong aftershock rocks the remains of the city, bringing down previously damaged buildings, triggering additional landslides, and creating fear and chaos.

At the DC's office, a team is sent on foot to inspect the Thuampui Helipad to see if it can be used for relief operations. Because the helipad is far from the city center, the NRDF teams that should come in by helicopter by morning will need to land at the Assam Rifles' parade ground. Assam Rifles begins to move people who have congregated on the parade ground elsewhere to make room. People also assemble at Rajiv Gandhi stadium, and the Chite Mini Sports complex, where helicopters are able to land. Rumors begin to circulate, fueling fear.

As night falls, many people remain at the site of their collapsed houses, trying to salvage items, aware of the risk of more aftershocks. Many people burn whatever they can get to keep warm and for light. Families that have not yet fully reunited become more anxious regarding the safety and location of remaining family members. The locality food teams start preparing to cook and serve food from the few items they collected locally. As night falls, churches hold prayer meetings of those assembled and sing hymns to bring peace and comfort. Surviving church leaders prepare to work through the night to comfort and support those in their congregations who have lost homes and loved ones.

By the end of the day, local government and medical officials fully understand that they are dealing with a major disaster. The formal assessment has not begun, but everyone knows the city is isolated, and the demand for life-saving help exceeds what is possible. The number of casualties and their severity, the extent of building damage, and the number and location of road blockages clearly exceed all expectations. Local officials have not had meaningful communications with officials outside of the area, and they are just beginning to know which officials, government and medical workers are among the casualties. The Assam Rifles have established limited communications with outside resources.

Day Two

NDRF teams from Kolkata and Guwahati arrive at Lengpui Airport and are transported to the Assam Rifles parade ground by helicopter. They bring in much needed emergency communications, including satellite phones. The team is debriefed by the CDMC and they send immediate needs requests to the NDMA. A team also lands at Thuampui helipad bringing in search and rescue and medical teams. Some medical teams are taken to the Civil Hospital, and some remain at the parade ground, which is one of the few open areas in Aizawl where field hospitals can be set up. The search and rescue teams are escorted to several nearby areas where many people are thought to be trapped alive under collapsed buildings. With so many collapses, a still-unclear picture of the location of the most heavily damaged areas, and most streets blocked by debris, the CDMC decides that the teams should focus on the closest locations of major collapses and work their way outward as new information comes in and some progress is

made in clearing major streets. The number of collapsed buildings overwhelms the few professional teams. Untrained volunteers conduct most search and rescue efforts.

The CDMC calls for construction teams to establish road access by clearing landslides on NH 54 to Silchar and the road to the Lengpui airport. Crews begin removing building debris and abandoned automobiles along the spine road. Debris clearance is slowed at collapse sites with trapped persons inside. There is very little space to use as a staging area for the relief materials coming in by helicopter. The Indian Army comes in with additional reinforcements and starts providing relief, assisting in the rescue efforts and establishing communications and road access. They provide mobile hospitals. The first badly injured victims are evacuated to Lengpui Airport on return helicopter flights, and are then sent onward for medical treatment.

The Central Government declares assistance to the Government of Mizoram. The Prime Minister appeals to the public to contribute to the PM's relief fund to help the Mizo community through the crisis. Indian and India-based international television, radio and print media make their way toward Aizawl as the government allows a limited number of journalists to board flights to Lengpui Airport carrying relief. A very few journalists are able to fly into the city in Indian Army helicopters. The story quickly goes global, raising worldwide concern.

LDMC first aid teams make their way to hospitals to assist, after providing whatever help they could in their own locality. Some members of these teams join search and rescue teams.

Beginning on the second day, shelter teams organized by local YMA branches clear some areas to accommodate the survivors. Many survivors are elderly citizens who had been alone at home and are now worried about their family members and in need of water and food. The trauma counseling team members counsel them, but they themselves are traumatized by the losses of family members and the scenes around them. They carry on with their duties. Shelter team members begin to set up shelters in the cleared areas. They also create temporary toilets near the shelter area, taking care to construct temporary soak pits for onsite disposal of wastewater, because any leakage could affect communities living downhill. The Food and Water team in the LDMCs start collecting more food supplies, and many shopkeepers give away food items to these teams. By the end of the day, the implications of failed infrastructure—loss of roads, electricity, communications, water supply—become clear, and the need for strategic decisions and resource allocation becomes evident. As on day one, the number of collapsed buildings overwhelms the few professional teams, so untrained volunteers conduct most search and rescue efforts. Members of the LDMCs are assigned to photograph and document dead bodies.

CDMC recognizes the need to provide information to victims regarding safety measures, location of medical services, food and water, and to counter rumors. Only FM radio provides connections, though limited, to the community.

One Week

An exodus from Aizawl starts as significant numbers of residents begin long treks to ancestral villages. Many people cannot get automobiles and motorbikes out of Aizawl because of damage to the urban streets and rural roads. Lorries carrying relief supplies and emergency vehicles congest all open roads. Many families remain because of uncertainty regarding the fate of family members. Able bodied family members will remain, trying to salvage materials for later use. Residents take risks to remove belongings from damaged buildings. The mood changes, as some of those staying behind become angry because of the losses and the lack of resources. Disaster

workers and government decision makers show the strain from the pressures, long work hours, and personal losses. Work to remove landslides and re-establish roadbeds continues. Heavy-lift helicopters deliver earthmoving equipment and temporary bridge structures to damaged sites. Decision-makers grapple with where to put all the debris, created by collapsed buildings and landslides, once it is removed from the streets and pathways. People prevent clearance of building debris from the spine road because they hold out hope that family members trapped in collapsed buildings blocking the road are still alive and can be rescued.

Providing potable water becomes critical as home tanks that survived the shaking begin to run dry. Desperate search and rescue efforts are at full force, with Indian and foreign teams who find and rescue several trapped survivors one week after the event. Funerals and burials for several hundred victims are held each day.

Two Weeks

Debris clearance has opened limited access along the spine road, but most roads remain closed by building debris and landslides. Continued aftershocks unnerve those remaining in the city, cause additional landslides, and exacerbate building damage.

The SDMA must make decisions about damaged structures: which can be used, which can be repaired, and which must be pulled down. Adding to the difficulty, there are no standards to evaluate badly damaged buildings regarding the risk of collapse in an aftershock, so the government must rely on the judgment of individual engineers. There are too few qualified engineers with training regarding the safety of damaged buildings and whether they can be repaired. At the end of the week, only a few damaged buildings are evaluated for safety.

The national news media and citizens of Aizawl begin asking why did this happen? Why were so many buildings damaged? Why did so many die?

Recovery and Economic Impact

With the response phase still ongoing, early recovery begins. This section describes anticipated challenges and timelines for recovery. The pace of recovery depends to a great extent on the resilience of those affected and on outside support. The objective is for individuals, institutions, government agencies, businesses and communities to resume increased levels of activity and to establish a new normal somewhere near the level of activity before the earthquake struck.

Aizawl's recovery would take years, probably longer than a decade. With so many buildings destroyed, many families' major assets would be gone, and a number of families, having lost family members, have lost the ability to earn an income. Students drop out of school to work on reconstruction to provide an income for their family. Residents would expect the government to provide large amounts of financial assistance just to get people back in minimal housing. Large sections of the commercial core, which contains vulnerable, older concrete buildings, would be decimated by building collapses and badly damaged, non-repairable buildings. Many shops and businesses would close due to a loss of their buildings, records and inventory. Economic development would be set back significantly.

Despite Aizawl's tremendous civil society and tight-knit communities, recovery would be very challenging. The devastation would be so severe, and the lack of water and power would persist for so long, that many would leave for villages where they have relatives and roots.

The timeline below highlights some key points in Aizawl's recovery from the scenario event.

One Month

Limited amounts of electricity from the grid would be available at substations, and dedicated lines would restore power to critical lifelines, such as the hospital and key government offices. A few schools would reopen, in an effort to provide children and families with some sense of normal life. Access to and within Aizawl is still severely limited. Aftershocks would increase damage and unsettle residents; damage and safety evaluations would need to be repeated for buildings that suffered substantial additional damage.

Three Months

Debris would be removed from key roads, and some road traffic would be possible within the urban area. Petrol for private use would still be in limited supply. Assessment of damaged buildings to determine whether they can be repaired would be ongoing. Electricity would reach distribution substations, and treated water would reach zonal tanks. However, electrical and water service would not yet reach most homes.

Six Months

Roads would still have limited capacity as repairs continue. Some damaged buildings would have been demolished, and construction of a few new buildings would begin. The geography, small spaces, limited supply routes, and lack of materials and workers restrict the pace of construction.

One Year

Though a significant amount of debris would have been removed, and many irreparably damaged buildings would have been demolished, damaged buildings and piles of debris would still dominate the cityscape. The population would be about one-third of the pre-event population. The city and state governments would have agreed on a rebuilding plan that prioritizes earthquake and landslide safety.

Actions to Improve Earthquake Safety and Resilience

As you have read in the scenario, widespread damage to buildings from shaking and landslides leads to casualties and to demands for rescue, medical care and shelter. But such extensive damage and consequences do not have to happen. New buildings can be located away from hazardous areas and constructed to resist shaking. The electrical and water systems can be made more robust and redundant. Key equipment can be secured, and backup systems installed at key facilities. New pipelines can be located away from areas of high landslide hazard and made flexible to help accommodate movement during an earthquake. Emergency response capacity can be enhanced, and plans can be made and tested to improve response capacity and the efficacy of coordination with outside assistance. Families can safeguard their homes and prepare each person for a role in responding to an earthquake.

Unacceptably risky situations can be rectified over time. For example, communities in hazardous landslide zones can be moved, active slides shored up, and vulnerable hospitals and emergency facilities retrofitted or replaced. Obsolete buildings can be replaced with safe new ones to improve safety and resilience over time. Hazardous landslide zones can be identified and measures taken to stabilize slopes. The city can install an effective surface and wastewater conveyance and drainage system to reduce the risk of landslides.

These are only a few of the many things that Aizawl's leaders and people can do together. Dedicated professionals in Aizawl have invested their careers to create a safer city, and they have already saved many lives. They need support—from you, from neighborhoods, from government agencies.

What Can Aizawl's Leaders Do to Prepare?

We recommend that the Government of Mizoram create a standing Geologic Hazards Commission to plan, coordinate and oversee measures to improve earthquake and landslide safety, including the following highest priority recommendations:

- Develop a better understanding of geology, topography and landslides by mapping and monitoring; as well as a better understanding of the effects of drainage and of constructing roads, buildings and infrastructure on landslide hazard areas.
- Identify and evaluate areas of high landslide hazard, beginning with those that affect large numbers of people and critical facilities, and determine appropriate risk reduction measures.
- Implement a comprehensive program to improve the system for surface water drainage and disposal of wastewater and sewage.
- Regulate slope cutting and slope modifications, and enforce the regulations.
- Enforce the building regulations.
- Encourage people to willingly comply with the site development regulations and building regulations, and provide standard building, foundation and site preparation plans and guidelines.
- Create local amendments to the National Building Code (in the building regulations) to address slopes.
- Require a seismic retrofit of buildings when significant additions/alterations are made.

- Prevent land allocation for building construction in geologically hazardous areas (“no build” areas).
- Review development plans, including the current Master Plan, with respect to this earthquake scenario and new geologic information.
- Utilize the current Master Plan and future revisions to expand Aizawl in a planned manner that properly accounts for geologic hazards. Discontinue incremental, unplanned development practices.
- Provide technical capacity within agencies to understand and properly use information related to earthquake and landslide hazards.
- Build the capacity of local geology, geotechnical engineering, structural engineering, architecture and planning communities.
- Modify one major ground transportation link– for example, NH 54 to Silchar– and the road between Lengpui Airport and Aizawl to remain functional after a damaging earthquake, by installing engineering measures to prevent landslides and strengthening bridges, in order to allow relief supplies to get in and people to get out.
- Identify, assess and reduce vulnerabilities of important buildings such as hospitals through replacement, change of use, strengthening, or land stabilization.
- Test state, district, Aizawl city, and locality disaster management plans with tabletop exercises, and strengthen them based on findings.
- Prepare a long term (i.e., until 2030) action plan that describes mitigation measures for Aizawl city and identifies responsible agencies and resources.
- Conduct outreach and awareness programs to promote family earthquake and landslide preparedness, and encourage families to prepare.

Several additional recommendations were identified as very important but as having slightly lower priority or potential impact on Aizawl’s overall level of risk. These additional important recommendations are:

- Assess utility systems, and increase the robustness of the systems to provide continuous service for critical facilities.
- Conduct school earthquake and landslide safety programs.
- Develop a post-earthquake reconstruction and recovery plan.
- Provide local heavy search and rescue capability; possibilities include a National Disaster Response Force battalion or enhanced State Disaster Response Force battalions.
- Increase the number of local first responders with adequate basic training in light search and rescue, first aid, and other immediate response tasks.

What Can I Do?

You can play an important role in helping to make your family and your community safer. You can begin making choices—today—that will increase your safety and bring peace of mind. You can do many things, most of which are simple. Here are some of them:

- Create a family emergency plan. Discuss with the entire family what you will do following an earthquake, major landslide, or other hazard event and how you will reunite. Determine a meeting place and an alternate location. See the sample plan online: <http://www.geohaz.in/upload/files/important/familypreparedness.pdf>
- Create a family emergency kit that contains emergency food, water, medicine and other essential items. See the State Disaster Management Authority website for a list of items to include: <http://dmr.mizoram.gov.in/page/disaster-survival-tips.html>
- Take the advice of qualified professional geologists before modifying any slopes on your land. Cutting slopes can be dangerous: slope cutting led to two of Aizawl's deadliest landslides, at Hlimen Quarry and Laipuitlang.
- Don't undermine your neighbor's house when building your own. Their house could slide down into yours!
- Install proper drainage and sewerage systems so that rainfall runoff, wastewater and sewage will enter drains or pipes, rather than soak into the ground. Keeping the slopes on your land as dry as possible will reduce the landslide hazard.
- If you build a semi-pucca or reinforced concrete (RCC) building, hire a qualified engineer to design it according to the Aizawl Building Regulations, and hire skilled, experienced masons to build it. Ensure that the masons follow the approved drawings. Buildings designed and built to the regulations typically cost about 5% more than those that are not, if anything, and they are much safer.
- If you build an Assam-type house, hire skilled carpenters and ensure that the support posts below the floor have plenty of X-shaped cross braces.
- Ask a structural engineer whether your home has the support to withstand a moderate earthquake, and find out what you can do to strengthen the structure.
- Obtain training in basic first aid. You just might save someone's life, maybe in your own family!
- Support government programs to reduce earthquake and landslide hazard; see the recommendations in the previous section.
- Learn more about earthquakes and landslides, and teach your children, friends and relatives. The more you know, the easier it will be to make your family and yourself safer.

Detailed Recommendations

The scenario highlights many issues that contribute to earthquake and landslide risk in Aizawl. Working together, Aizawl's people and colleagues throughout India and beyond can begin to address them. The tables in subsequent sections present concrete recommendations to address each separate issue identified during the course of developing the scenario and through consultations with local professionals and community members. Recommendations and the issues they address are organized by major topics:

- Systemic concerns
- Landslide risk
- Building vulnerability
- Infrastructure vulnerability
- Scientific data needed to characterize hazard
- Land use planning

- Public education and awareness
- Response and preparedness

Within some of these major topics, recommendations to address issues are organized into separate sub-sections for policy, technical, and professional community development issues.

Aizawl's people and their leaders must set the priorities and determine which issues to address first. We recommend that the first task of the recommended Geologic Hazards Commission should be to set priorities through an inclusive action planning process.

<i>Systemic Concerns</i>	
Issue	Recommendation
Limited policies, regulations and incentives to address hazardous areas	Create a standing Geologic Hazards Commission to develop land use policies, regulations and incentives. This advisory body should be independent of government control, transparent, and have members from multiple technical disciplines and organizations. (A separate Landslide Policy Committee will address some items related to landslides.)
No coordinated program or plan to address earthquake and landslide risk in Aizawl	Develop a long-term action plan for a safer Aizawl (i.e., until 2030), which describes mitigation actions, responsible agencies, and resources. The plan would work in parallel with the Master Plan, to coordinate initiatives and programs. The Geologic Hazards Commission would develop and oversee implementation of the action plan.
	Design and implement comprehensive earthquake and landslide risk reduction programs, which the Geologic Hazards Commission would oversee.
Lack of drainage systems and wastewater systems contributes to landslides, poor sanitation, and contamination of groundwater, streams and rivers	Implement a comprehensive program to improve the limited system for surface water drainage and disposal of wastewater and sewage; to provide a sewage treatment system; and to eliminate septic systems and soak pits that saturate slopes with contaminated water. The Asian Development Bank funded improvements will make significant progress toward achieving these goals.
Geographic isolation and lack of transportation infrastructure greatly impedes post-earthquake relief and early recovery	Modify the road to Lengpui Airport plus one major road link, perhaps NH 54 from Silchar, to remain functional after a damaging earthquake, by mitigating landslide risk with engineering measures (for example, installing reinforced concrete retaining walls) and strengthening bridges. This will enable relief supplies to get in and people to get out immediately following earthquakes or major storms. Focus on making major improvements to these two roads rather than

	distributed, incremental improvements to several.
	After one road link is modified to remain functional (see above), improve quality—and eventually number—of other road links with neighboring states.
	Increase the number of open spaces in and near the city that can be used for helicopter access for relief efforts.
	Create “pods,” sections of the city that can be self-reliant after earthquakes for about one month, by storing food, water, tools and medical supplies locally and training residents in basic first aid and light search and rescue.

<i>Landslide Risk</i>	
Policy Issue	Policy Recommendation
Landslide hazard maps are not currently used to create regulatory zones that directly link to landslide risk reduction policy actions, and policies have not been adopted	Create landslide risk zoning and regulatory zoning maps from landslide hazard maps at a scale of 1 to 10,000.
	Adopt and implement policies that use information on landslide zoning maps to restrict development and to mitigate the hazard and risk in already developed areas.
	Develop a culturally—and economically—sensitive way to relocate persons out of hazard areas.
	Put a program in place for review and enforcement of policies.
No regulations on surface modification or slope cutting; many instances observed in which people cut land and undermine their neighbor’s property	Enact a site development ordinance to regulate earthmoving/disturbance of land surface.
	Use the site development ordinance to prescribe setbacks from neighbors, to prevent adverse effects of slope cutting such as undercutting adjacent buildings.
	Develop a program for review and enforcement, including sufficient AMC enforcement staff.
Land Revenue and Settlement does not have access to appropriate landslide hazard maps when giving land settlement certificates that allocate land for building, leading to allocation of house sites in areas of	Strengthen Mizoram Land Revenue Act to better consider landslide hazard when giving land settlement certificates and allocating house sites.
	Develop regulations for dividing parcels of land that consider landslide hazard.
	Define no-development zones using technically robust

high landslide hazard	geologic information, and enforce them.
	Provide international-standard geologic hazard maps at a scale of 1:10,000 and information on landslide hazards to Land Revenue and Settlement.
AMC does not have appropriate scale and quality landslide hazard maps for issuing building permits	Strengthen existing permitting system and use landslide hazard maps at a scale of 1:10,000 or better that conform to international standards.
	Require measures to address local and neighborhood-wide hazards.
AMC notification (approval of building permit) requires geologist to inspect certain building sites and issue no objection certificate, but this is a difficult judgment to make without better information and clear public policy	Add an AMC geologist/geotechnical engineer to review plans when issuing building permits
	Create a Geologic Review Board of three to five geologists and geotechnical engineers to review EVERY geologic report, map, and ruling to improve credibility and consistency, provide support for difficult decisions (one geologist is not enough; a team is needed to face upset owners and to raise the professional standard-of-care).
Geologists asked to make recommendations on safety of sites without sufficient geological information or sufficient policy direction.	Increase funding for geological and geotechnical data collection at sites through increased permit fees (perhaps fees can vary with landslide hazard zones or other regulatory zones defined using improved landslide susceptibility maps).
Due to lack of policy or legal grounds, courts have overturned AMC's and geologists' recommendations not to allow development in areas of high landslide hazard	Educate courts on the public safety impacts of allowing buildings to be constructed in areas of high landslide hazard. Articulate the rationale in terms convincing to the court. If necessary, seek changes to relevant laws.
Limited policy mechanisms to carry out mitigation measures affecting multiple parcels, utilities and roads	Develop policy options such as: <ul style="list-style-type: none"> • Government purchases land in very high/high landslide hazard areas and relocates the people living there • Create a geologic hazard abatement district / Block/ Ward (administrative district in landslide hazard areas to create area-wide action).
No mechanism to bring policymakers and geologists together to develop coordinated policies based on sound geologic information	Short-term: Use the multi-departmental, multidisciplinary Landslide Policy Committee for Aizawl City to address policy issues and laws identified in this section (AMC has already formed this committee, which is not the same as the Geologic Review Board recommended above.)
Quarrying operations can	Increase oversight of quarries and limit quarry locations.

destabilize slopes	Provide training for quarry workers and owners in safe operations and safer methods for quarrying.
	Prohibit house site allocation, new residential construction or quarry worker housing in areas that professional geologists determine could be affected by quarrying activity.
Technical Issue	Technical Recommendation
Very limited and incomplete landslide inventory information	Create a landslide inventory categorized by landslide type and bedrock structure. To do this, obtain historical information, collect field data and obtain maps at a scale of 1:10,000 or better.
Landslide susceptibility maps and hazard maps for Aizawl could be significantly improved by including more information on local geologic structure and existing landslides	Improve landslide susceptibility maps by providing maps at 1:10,000 scale or better and including geologic structure and existing landslides. Maps should be made to international standards (i.e., Fell et al. 2008 ²). Maps at 1:1000 scale or better, to facilitate regulatory use, should be the eventual goal.
	Create landslide hazard maps to international standards (i.e., Fell et al., 2008), based on susceptibility maps, at a scale of 1 to 10,000 or better. Maps at 1:1000 scale or better, to facilitate regulatory use, should be the eventual goal.
No landslide hazard maps for critical infrastructure, such as roads to the airport, water pipelines, high voltage transmission lines and substations	Develop strip maps at 1:10,000 scale or better for critical infrastructure outside main city (i.e., water pipelines down to raw water intake and treatment works, road to Lengpui Airport).
Limited capability to interpret and apply geologic maps and conditions that are precursors to rapid onset slides, and limited capability to take action	Build the technical capacity of local geologists. The Geologic Review Board recommended above and the “landslide hazard circle” in Department of Public Works (see below) would help achieve this.
	Develop an early warning system for elevated landslide hazard conditions.
Limited local capacity to design mitigation measures	Create a “landslide hazard circle” within the Department of Public Works to provide consistent, state-of-the-art engineering for mitigation projects carried out by the government. These projects would be reviewed by the Geologic Review Board recommended above.

² Fell, R., Corominas, J., Bonnard, C., Cascini, L., Leroi, E., Savage, W.Z., and on behalf of the JTC-1 Joint Technical Committee on Landslides and Engineered Slopes (2008): Guidelines for landslide susceptibility, hazard and risk zoning for land use planning. *Engineering Geology*, Vol. 102, Issues 3-4, 1 Dec., pp 85-98.

	Require government and private engineers to obtain training on landslide hazards and mitigation measures.
No mitigation measures in place for most known existing landslides that endanger people	<p>Where appropriate, implement specific mitigation measures that may include:</p> <ul style="list-style-type: none"> • Flexible barriers • Reinforced concrete retaining walls • Excavation, grading, compaction, shear keys • Subsurface and surface drainage systems • Check dams • Geotextile and reinforced earth systems • Soil nailing • Rock bolting • Bridge over failure zones • Replanting cleared areas • And many more locally appropriate solutions
Portions of water system, electrical system and roads have been damaged by landslides or are in areas highly susceptible to landsliding	Institute a program to make infrastructure more robust in locations at high risk of landslide damage
Important buildings threatened by landslides	Assess landslide hazard at important buildings (i.e., hospitals, fire stations and key government response agency offices); stabilize slopes or relocate critical functions to safer buildings.
Professional Community Issue	Professional Community Recommendation
Lack of organized engineering geology and geotechnical professional organizations results in individuals taking sole responsibility for their judgments without peers to develop a standard-of-practice or collaborative bodies to discuss technical information and judgment	Build a professional community of professional geologists and geotechnical engineers; build capacity by supplying information and encouraging professional interaction. The Geologic Review Board and required training recommended above will contribute to this.
Limited or no engineering geology or geotechnical engineering higher education available locally	Provide civil engineering, geotechnical engineering and engineering geology undergraduate and graduate education at local universities; National Information Centre for Earthquake Engineering (NICEE) outreach would be one way to do this.
Few professional geotechnical engineers practicing in Aizawl	Develop an incentive program to attract geotechnical engineers to Aizawl.
	Encourage higher secondary students in Aizawl, who plan to pursue civil engineering studies, to consider geotechnical engineering.

Building Vulnerability	
Policy Issue	Policy Recommendation
AMC has limited ability to demolish unsafe or illegal buildings; current mechanism for government to remove dangerous buildings is via Deputy Commissioner's office	Develop policies and/or regulations necessary to provide AMC with authority to remove dangerous buildings, or to coordinate with the Deputy Commissioner's office to remove them.
No guidance or process for determining when buildings in the area of a landslide may be unsafe, and for preventing occupancy of unsafe buildings	Develop policy and process by which AMC determines under what conditions buildings are unsafe to occupy.
	Enact regulations necessary to authorize AMC to declare buildings unsafe and to force occupants and owners to comply with placards.
AMC building regulations do not include consideration of slope	Revise building regulations to consider slope, by adding special provisions that supplement the National Building Code.
	Consolidate development regulations in a single integrated process that considers landslide hazards and that encompasses land allocation, land division, site development and building permit approval.
Many owners dismiss architect or engineer after receiving AMC approval, due to AMC lack of building code enforcement	Require architect/engineer to observe construction and sign off on as-built conditions prior to occupancy (i.e., completion certificate), and enforce requirement.
Lack of policy options for addressing dangerous buildings and buildings that project into set back areas.	In addition to demolition, provide policy support for options such as: <ul style="list-style-type: none"> • Prevent additions • Encourage replacement • Buy out owners • Encourage appropriate retrofit measures
Lack of policy options to address very large number of seismically vulnerable buildings	Require seismic retrofit when significant additions are made to existing buildings.
	Develop additional policy measures that encourage replacement or appropriate retrofit measures.
Technical Issue	Technical Recommendation
Structurally safer buildings are surrounded by structurally unsafe buildings, which jeopardize the safer buildings	Restrict new building construction on landslide-susceptible slopes, as part of development plans. (Partially implemented in Master Plan.)
	Enact laws that require hazard abatement through either strengthening or removal of hazardous buildings.
Characterizing building	Government of India agencies should support and continue

vulnerabilities is difficult due to lack of data and analysis	research begun after the 2011 Sikkim earthquake on hillside building seismic behavior, which would also be applicable to many hill areas in India, not just Aizawl. Support work by researchers throughout India, including those outside the northeast.
	Install instruments at two or more local buildings to measure seismic shaking to learn more about response characteristics of local building types, including hillside buildings and traditional timber “Assam-type” buildings.
Many important buildings are seismically vulnerable	Conduct a program to assess and replace or retrofit important buildings, beginning with critically important buildings such as Aizawl Civil Hospital.
	Conduct a program to assess and replace, retrofit, relocate or stabilize slopes at vulnerable school buildings; include private schools by enacting laws that require the above actions.
Pounding together of adjacent buildings with floors that do not align, which can cause collapse	Enforce setback regulations for new construction or renovation.
	Educate owner-builders about the dangers of building too closely to neighboring buildings.
	Enact laws mandating owners to address pounding (tying buildings together, armoring weak-mid column areas, adding energy absorbing material, etc.).
Code does not provide adequate guidance for constructing buildings on slopes common in Aizawl	Develop special provisions for design of hillside buildings to address slope issues.
Owner-builders may not be able to afford to hire a qualified engineer, architect or geologist	Develop and provide standard building, foundation and site preparation plans and guidelines.
Limited ability to conduct geotechnical laboratory testing necessary for proper design of building foundations	Promote the geotechnical engineering and engineering geology professional good practice of collecting and testing geotechnical material samples.
	Augment the capacity of PWD’s current laboratory to create a fully equipped geotechnical materials testing laboratory, and provide necessary equipment to sample materials and run in situ tests.
	Develop a pilot program at government level to sample and perform testing at numerous representative or “test” sites from which data could be used for projects at geologically similar sites.

No specific retrofit guidance for buildings on slopes	Develop retrofit guidance and prescriptive measures for commonly encountered building configurations.
No specific retrofit guidance for Assam-type buildings	Develop retrofit guidance and standard “pre-engineered” retrofit plans.
Poor quality re-rolled reinforcing steel from Silchar is widely used	Set standards for reinforcing steel material properties.
	Ban import and use of steel that does not meet these standards.
	Educate owner-builders about deficiencies in re-rolled steel, possibly teaming with Tata or other reliable brands in a marketing campaign.
Professional Community Issue	Professional Community Recommendation
Lack of a professional organization for engineers and architects to speak as one voice, support learning, develop a standard-of-practice, or support each other in carrying out improved practices	Provide a platform for architects and engineers to stand together on quality construction.
	Strengthen local engineers’ and architects’ associations.
Owners, city officials, contractors and workers do not understand earthquake behavior or value measures needed to resist earthquakes	<p>Educate homeowner/builders about:</p> <ul style="list-style-type: none"> • earthquake risk • construction practices that minimize earthquake and landslide risk • the need to employ professional architects and engineers
Many local engineers lack specialized earthquake engineering training	Build capacity of local architects and engineers to design, analyze and retrofit buildings to improve seismic performance.
Uneducated non-local masons from neighboring states construct most buildings in the city	Educate employers and foremen; have requirements for oversight.
	Provide training for non-Mizo masons.
	Develop a more professional network of builders and contractors for building construction.
Local carpenters do not necessarily employ earthquake resistant features in Assam-type houses	Provide training for Mizo carpenters.
AMC does not have enough staff or the training needed to inspect buildings under construction	Improve AMC and ADA enforcement of building regulations. Find a source of income to support the additional effort and training.

Infrastructure Vulnerability	
Technical Issue	Technical Recommendation
Road to airport has several areas of ongoing landsliding	Implement mitigation measures in problem areas.
Damage to the transportation system and need to prioritize life-saving actions will delay delivery of fuel, and repairs	Plan for transportation disruptions by keeping an adequate supply of fuel on hand. Establish a strategy, and build the capacity, to remove multiple landslides after hazard events. Build on existing PWD experience and strategies for clearing roads after heavy monsoon rains.
Aizawl lacks comprehensive storm water, wastewater and sewerage systems, creating multiple problems	See Systemic Concerns section.
Understanding of earthquake and landslide vulnerabilities of critical utility systems is limited and fragmentary, and mitigation options have not been developed in most cases	Identify, prioritize and complete full walkdowns of critical infrastructure for earthquake and landslide vulnerability.
	Develop, prioritize and implement mitigation options to improve service delivery and reduce interruptions.
	Increase the robustness of critical utility systems to provide continuous service for one or more critical facilities.
Water system relies on electrical power for pumping up to ridgetop main reservoir for distribution	Provide backup diesel pumps for raw water pumps.
	Provide sufficient diesel storage to power all backup water pumps for predicted length of electrical power outage caused by earthquake.
	Provide backup water source for critical facilities such as hospitals.
Water system is not redundant: there is one source and one main ridgetop reservoir through which all water passes	Add redundancy as the water system expands.
	Anchor individual family water tanks to prevent toppling during an earthquake to protect distributed water supply.
	Develop additional rainwater harvesting capacity at existing public buildings; mandate for all new public buildings.
	Promote rainwater harvesting at private buildings and homes.
	Develop water rationing plan as part of post-earthquake response plan.
	Develop an emergency water delivery plan that considers blocked roads and streets following earthquakes.
Rigid pipe connections can break	Install valves to control stored water when pipes and

and drain water from the system	connections break.
	Install flexible connections.
	Install flow monitoring systems.
Generators, electrical equipment and fuel tanks not anchored to resist earthquake shaking	Seismically protect water system's electrical equipment (generators, motor service centers, etc.) used for pumping and treatment.
Electrical equipment in substations not seismically protected and prone to damage that may cause lengthy service interruptions	Seismically protect electrical power system equipment in substations.
Communication systems will not work because of convergence, damage, loss of electrical power to transmitters, switches, towers, etc., and to individual battery powered devices	Set up backup communication systems. Prepare a Communications Plan for the State.
Loss of broadcast media hampers ability to disseminate information following an earthquake	Designate one station as an emergency public communication system. Locate it in an earthquake-resistant building, and provide robust emergency power and adequate fuel.
Loss of grid power will prevent mobile phone users from recharging phone batteries even if mobile service is restored quickly	Encourage people to keep small solar chargers to provide power for mobile phones (National Solar Mission of the Government of India could be a good partner).
Lack of solid waste/refuse disposal	Implement Master Plan recommendations on solid waste.
Lack of understanding of infrastructure vulnerabilities and interdependencies	Develop a detailed scenario to anticipate problems and interdependencies and to clarify expectations of each infrastructure system.
	Create an inter infrastructure committee to consider infrastructure interdependencies and write a report on shared vulnerabilities and a long-term mitigation/post-earthquake operations plan.
	Sensitize and train those persons responsible for infrastructure to identify and mitigate earthquake vulnerabilities.

Scientific Data Needed to Characterize Hazard

Issue	Recommendation
No detailed geologic maps of Aizawl district or urban area	Carry out detailed geologic mapping in Aizawl urban area, including bedrock lithostratigraphy, joint structure and formation attitude, as well as Quaternary deposits, at a scale of 1:10,000 or better.
No topographic base map data at sufficient scale for detailed mapping	Obtain 3 meter or better digital elevation model data
Faults in the area have not been mapped in detail or characterized for seismic hazard potential	Because most the faults that contribute to Aizawl's seismic hazard are deeply buried, the Government of Mizoram should request that the Oil and Gas Commission make any subsurface data gathered in the State available to scientific researchers in India for hazard characterization purposes.
	Characterize faults that have been identified or inferred in previous studies.
	Contribute information to a Quaternary fault database for Mizoram and the region.
No array of seismic instruments to give insight into local ground motion attenuation characteristics, topographic amplification effects, and tectonic structures.	Install four to five instruments in Aizawl city to measure ground shaking and to gather data on topographic amplification effects. Department of Science & Technology or Indian Meteorological Department (IMD) could be potential supporters of this effort.
No array of GPS stations to record the direction and speed of ongoing tectonic movements	Install additional continuous GPS stations in Mizoram, including on Aizawl's main ridge and in the next valley to the east, to measure anticline growth and to reconcile regional tectonic movements.
	Tie these new instruments in with existing regional GPS networks. Provide additional staff resources for data compilation and interpretation at institutions operating existing networks.

Land Use Planning

(Most land use planning solutions are located in the landslide hazard and building vulnerability sections.)

Issue	Recommendation
The capacity of Aizawl as a urban area to survive the effects of an earthquake need to be evaluated in terms of both public safety and emergency transportation and circulation, and the effects of building and infrastructure damage and landslides	This scenario document begins to address this issue; other, more detailed scenarios can be developed to assist planners in determining the viability of the city, and the possibility for safe rebuilding in its current location, following a major earthquake. Based on the results of this evaluation, if necessary planners could begin to encourage development in more sustainable locations, including other cities.
	The action plan mentioned previously should include items identified as a result of this evaluation.
Landslide susceptibility map in Master Plan is strictly slope-based (the Master Plan does not use technically adequate maps), leading to zoning for proposed development in areas of presumed high landslide hazard	Review Master Plan versus scenario and newly available geologic information.
	Incorporate recently and newly developed, detailed hazard information and maps into Master Plan.
	Augment Master Plan to directly address building and land development practices and infrastructure vulnerability based on recently and newly developed hazard information and maps.
Past land use practices have allowed building construction in areas of high or very high landslide risk	Identify areas of active landslides or very high landslide risk that need to be addressed right away with planning and mitigation measures.
Master Plan does not adequately control risk over time	Develop measures (incentives, allowable uses and density, transfer of rights, re-subdivision, etc.) to expand the city in ways that will abate vulnerability. Infill projects that replace vulnerable buildings or stabilize unstable areas can reduce the risk.
Incremental unplanned development leads to slope destabilization, crowding and substandard infrastructure	Allow only planned development and discontinue incremental development by following Master Plan (amended to consider current geologic information) fastidiously.

Public Awareness and Education	
Issue	Recommendation
Public not aware of actions they can take to improve safety and reduce risk; not enough training and awareness at community level	Use shake tables to demonstrate earthquake effects on buildings.
	Use mass media such as television to present basic information on risk and preparedness.
	Create a credible scenario to: <ul style="list-style-type: none"> Promote education and awareness generate popular support for enforcement (the scenario in this document is a good start)
Few organized awareness activities in churches, especially social front and existing committees	See above
Effective family preparedness measures are lacking	Develop strategy to encourage and diffuse family preparedness measures.
	Develop incentives to promote family preparedness.
Women and children are not well prepared to manage on their own	Preparedness materials should take gender and age considerations into account.
	Conduct awareness and preparedness programs in schools.
Some government officials not aware of the level of earthquake and landslide risk or of options for reducing it	Raise awareness of government officials through individual meetings and formal awareness programs if necessary
People lack awareness of the earthquake hazard and risks posed by the geologic and built environments, and what they can do to make themselves safer	Install signs and “monuments” both marking and explaining key geologic features and major landslides.
	Open a store-front Hazard Center that can provide public information, classes, meeting space, etc.
	Engage civil society (YMA, Mizo Women’s Association, Mizo Elders Association, church groups, etc.) to explain hazards and protective measures and to provide assistance to their members in need.
	Find a way to reach private businesses and business leaders by providing information, involving them in other mitigation efforts, explaining impacts on businesses, identifying flagship businesses to provide leadership, engage service organizations (Rotary, chamber of commerce, etc.).

Response and Preparedness	
Issue	Recommendation
Current rescue teams may not be well coordinated to incorporate and manage influx of community members and volunteers trying to help	Create an emergency preparedness and response plan that fully engages the private sector and civil society, or augment existing plans.
Local rescue teams are not equipped with heavy lifesaving equipment, and post-earthquake isolation by landslides will restrict the ability to bring in outside equipment	Develop well-equipped local search and rescue teams by strengthening the State Disaster Response Force with more advanced training and equipment.
Professional responders are too few in number to respond to the large number of building collapses expected in even a moderate earthquake	Increase the number of local first responders with adequate basic training in light search and rescue, first aid, and other immediate response tasks.
Determining realistic ability to implement response plans given potential damage to key local infrastructure and resulting consequences	Review and assess dependencies of response plans on roads and local utility infrastructure, and develop contingency plans to deal with anticipated infrastructure damage.
Lack of open space in the city greatly restricts areas that response planners can designate for relief operations	Set aside additional open space in Aizawl Urban Area that can be used for relief operations.
	Preserve and expand open space in current Assam Rifles area when Assam Rifles relocate.
Water borne diseases due to water pipe and sewer pipe breakage are possible	Plan to provide water from sources other than piped supply.
Emergency shelters may not be earthquake resistant	Assess identified emergency shelters for earthquake resistance and seismically strengthen if needed.
Key response agencies, such as the Divisional Commissioner's office, operate out of buildings not designed to remain operational following a major earthquake and therefore building damage is likely to impair the response	Build an Emergency Operations Centre designed to remain operational following a major earthquake.

State, District and Local Disaster Management Plans are new and not well tested	Conduct tabletop and simulation exercises to test and refine the State, District and Locality Disaster Management Plans.
State, District and Local Disaster Management Plans do not address recovery or reconstruction	Develop recovery and reconstruction plans that coordinate with Disaster Management Plans and Master Plan; use plan as opportunity to prevent reconstruction in hazardous areas, improve access, and reduce congestion.
Damaged buildings and landslides will block streets, inhibiting transportation and relief efforts within the city	Consider developing self-reliant “pods” within the each locality where emergency supplies can be stored, so neighbor can help neighbor.

Appendices

A: Earthquake Sources and Shaking

B: Landslides

C: Buildings

D: Infrastructure

