



# Dhaka Earthquake Risk Guidebook

Bangladesh Urban Earthquake Resilience Project

February 2014



**GFDRR**  
Global Facility for Disaster Reduction and Recovery



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# **Dhaka Earthquake Risk Guidebook**

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# Executive Summary

This document is submitted in compliance with EMI’s contractual obligations to the World Bank for the Bangladesh Urban Earthquake Resilience Project. The Guidebook summarizes the earthquake hazard, vulnerabilities and risk assessment (HVRA) studies relevant to Dhaka, and explains the methodology for interpreting the outcomes of these studies and their applications in various developmental processes and in disaster risk reduction planning. The Dhaka Earthquake Risk Guidebook is a companion to the Dhaka Risk Profile and Atlas. The combined volumes represent a single reference on earthquake hazards, vulnerability and risks for Dhaka.

The HVRA analyses undertaken for Dhaka by this project rely significantly on previous studies such as the Comprehensive Disaster Management Program (CDMP) and on other published research on Bangladesh earthquake hazards and risks. In particular, the exposure data (i.e., quantification, characterization and spatial distribution of the assets at risk in Dhaka) was provided by the World Bank and was originally developed by the CDMP. The exposure data was used “as is” and no attempt was made to check its accuracy or completeness.

New and updated socio-economic data was collected and analyzed to develop the urban disaster risk indicators including the demographic structure of the population by ward.

This Guidebook is intended to serve as a reference that explains the relevance, methodology, process, and findings of the Earthquake HVRA conducted in Dhaka as part of the Bangladesh Urban Earthquake Resilience Project (BUERP). It provides an example of a framework for undertaking a HVRA in the context of urban disaster risk reduction (DRR). The elements of this framework may be followed for similar assessments in other cities in Bangladesh. The general approach to the assessment is participatory, with the project team working closely with the members of a Scientific Consortium and HVRA Focus Group (FG) to refine and validate the assessment methodology, analysis procedures and findings.

## HVRA Process for Dhaka

The aim of the HVRA component of the BUERP is to develop an understanding of the impact of earthquakes in Dhaka by assessing the location and magnitude of potential earthquakes, the resulting severity of ground motion and ground failure, and the consequent physical and socio-economic losses. It also includes the development of indicators, which combined physical impact to socio-economic factors of resilience.

The investigation process is composed of five phases as illustrated below, with the outputs of each phase contributing to the accomplishment of the objectives of the succeeding phases.



The HVRA Process for Dhaka

### Preparation

In the Preparation phase, initial scoping was conducted to identify the key individual and institutional stakeholders. This was accomplished through consultations with international and local experts, and the review of secondary sources of information. The identified experts were invited to form the Scientific Consortium, a small group of selected individuals with significant expertise in fields such as risk assessment, earthquake engineering, and geology/geophysics. Potential users and contributors of data were organized into the HVRA Focus Group, which represents a wide membership of organizations and institutions from the public and private sectors, the academe and civil society.

The key outputs of the Preparation phase were:

- Identification of key experts and stakeholders through review of secondary sources and consultations
- Creation of HVRA Focus Group
- Creation of the Scientific Consortium
- Determination of data needs and establishment of assessment database
- Development of investigation work plan and timeline.

### Data Collection

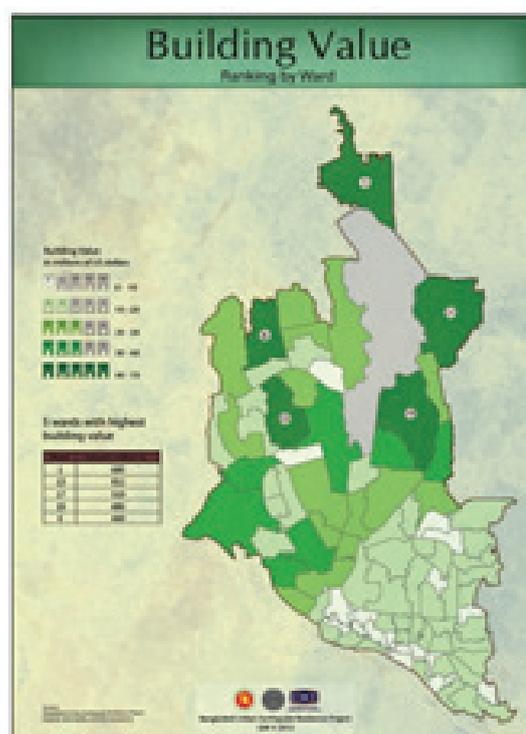
The HVRA for Dhaka required the collection of two general sets of input data: seismic hazard data and built-environment exposure data. Seismic hazard data provides the information on the geology, geomorphology, seismo-tectonic, seismicity, soil, site conditions, and earthquake energy attenuation characteristics. For this project, the needed data was primarily collected from a desk review of the study undertaken by the Comprehensive Disaster Management Program (CDMP), as well as other available scientific literature on earthquakes, particularly those that contain loss estimates and other disaster data.

### Exposure

For the earthquake loss assessment, the BUERP study relied significantly on the comprehensive inventory development performed by CDMP with supplemental data provided by RAJUK. The CDMP effort utilized a combination of government data, aerial imagery, and site surveys and provides exposure information for buildings, lifelines and population. The information is provided by cluster and integrated by ward.

The type of information provided on buildings includes: location, type of material, occupancy, number of stories/height, and value. Information on critical and essential facilities was also collected.

The map below shows total building value by ward.



Road network and water system and distribution network were provided by RAJUK. An exposure dataset was created and translated into a GIS system.

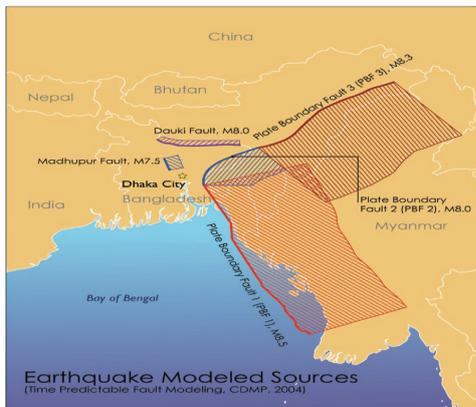
For the development of the Risk Indicators, additional data was collected to represent socio-economic parameters. These include information from the census data on the demographic structure of the population (population density, age, gender, literacy, disability, etc.); type of access to services (water, electricity, sanitation) and the type and location of resources and key facilities from other sources such as schools, hospitals and police stations.

**Seismic Sources and Ground Motions**

Five seismic sources were analyzed:

- » Madhupur Fault M7.5
- » Dauki Fault M8.0
- » Plate Boundary 1 Fault M8.5
- » Plate Boundary 2 Fault M8.0
- » Plate Boundary 3 Fault M8.3

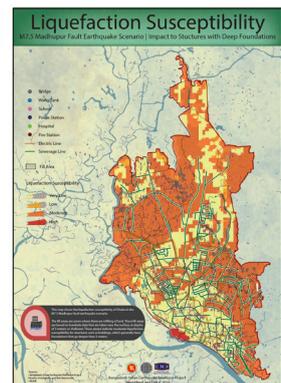
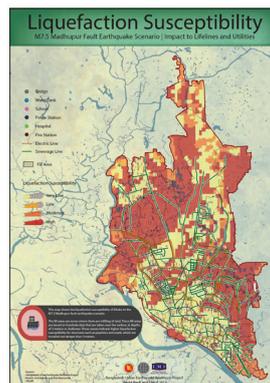
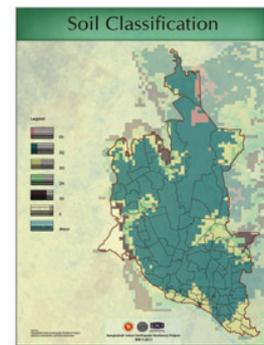
For the Madhupur and Dauki faults, four Next Generation Attenuation (NGA) equations used in the most recent versions (2010 and 2013) of the US earthquake hazards maps were utilized. For the Plate Boundary Sources, three subduction ground motion attenuation equations were considered.

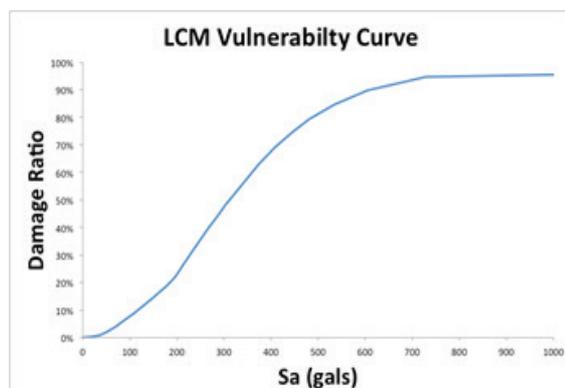


**Soil Classification and Liquefaction Potential**

The BUERP study utilized the detailed geological map developed as part of the CDMP study with further qualification by local geotechnical experts familiar with the soil and surficial geological conditions in Dhaka. The figure below shows soil classifications in the Dhaka area. Soil classes range from D1 (stiffest) to E (softest). Ground motions will be amplified more on the softer soils, especially in the high period (i.e., low frequency) range.

The figure on the bottom shows the liquefaction susceptibility map for the Dhaka region. One significant change was made to the liquefaction map produced by the CDMP study. The CDMP liquefaction susceptibility map identified a significant area of Dhaka as fill with very high liquefaction potential. Borehole data indicate the fill is mostly surficial in nature (<3 meters) and likely placed in low-lying areas as the city expanded. In the BUERP study, these areas were classified as having moderate liquefaction potential for building analyses (most building foundations are likely below the fill) and high liquefaction potential for buried utility lifelines.





### Vulnerability

Vulnerability functions relate the impacts of ground motion on buildings and contents. Fragility curves developed as part of the CDMP study were reviewed and converted into damage ratio curves (or vulnerability curves) suitable to the CAPRA analysis software. An example is shown above.

Lifeline and human casualty vulnerability were primarily based on the information contained in the HAZUS risk analysis software.

### Analysis and Diagnosis

For the BUERP study, the CAPRA suite of software developed by the World Bank was utilized for carrying out the core seismic hazard and building loss analyses. The CAPRA model is also used to undertake sensitivity analyses and to compare results with the CDMP findings. The working assumptions and methodologies behind CAPRA were also examined and shared with the Focus Group members and other specialists, in order for them to gain a better understanding of the use of the model and generate scientific consensus on the modeling approach and parameters.

Calculations related to liquefaction data and lifeline and casualty losses were performed outside of CAPRA, based on the ground motion output from CAPRA. These loss calculations were based on the methodologies outlined in the HAZUS software technical documentation developed by FEMA in the United States.

### Risk Output and Interpretations

Once output is generated from risk analyses it must be reviewed for accuracy, coherency and reasonableness. Basic quality assurance was performed to make sure that input data was coded properly and calculations were carried out correctly. The results from this study were compared with other studies including those in the CDMP reports. The section on HVRA findings below provides high level summary results.

### Stakeholder's Validation

The HVRA Focus Group, Advisory Committee, and Scientific Committee were set up to provide input and guidance during the entire course of the project. Several meetings, workshops, and consultations were undertaken during project implementation to accomplish the goals of the participatory process. In December 2013, a final project field investigation was performed in Dhaka with the goal of presenting results and getting feedback prior to the completion of the Risk Atlas and Guidebook. The participants were able to review the methodology and outcomes one more time and participate in a validation process as well as provide input on the content of the HVRA Guidebook and the Dhaka Risk Atlas. The input from the stakeholders was incorporated in the final versions of these documents.

### HVRA Findings

Results are presented for three event scenarios, namely:

- A magnitude 7.5 event on the Madhupur fault;
- A magnitude 8 event on the Plate Boundary 2 fault;
- A magnitude 6 event at an arbitrary location under Dhaka representing the possibility for a more moderate event in closer proximity to the city.

### Scenario Ground Motions

These maps show ground motion distributions (peak ground acceleration) for the three scenarios. Each of these events results in strong to severe ground shaking in Dhaka and the maps show that all areas of Dhaka are subject to potentially strong ground motions.

### Scenario Building and Contents Losses

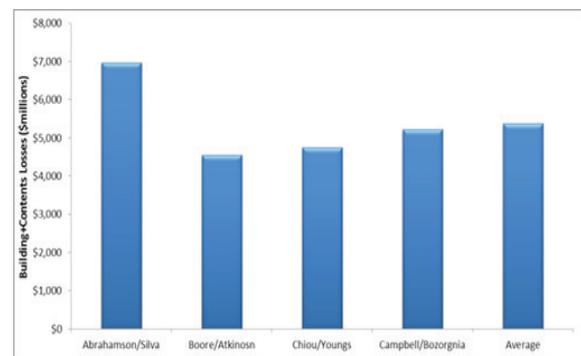
The first chart in the next page shows estimated combined buildings and contents losses for the three events. Total losses are in the range of \$5 to \$7 billion. Total estimated exposure values are approximately \$17 billion buildings and \$11 billion contents. Therefore, losses represent approximately 25% of total exposed values. Also shown in the chart are estimated losses from the CDMP report. Overall, losses are quite consistent between the two studies.

In addition to looking at financial losses, damage state distributions are useful in understanding the overall physical damage to the building stock in an event. Out of the estimated 327,000 buildings in Dhaka, the second chart on the next page shows how many are in each of four damage states for the Madhupur M7.5 event where 30% of the buildings are modelled to be in extensive or complete damage states.

There are numerous uncertainties associated with the parameters that make up an earthquake risk analysis. In the case of Dhaka, these uncertainties are particularly acute since the earthquake hazard has not been investigated fully. When performing a risk analysis, as a means to understanding these uncertainties, it is helpful to test the sensitivity of results to alternate modelling assumptions. The charts below show three examples of alternate modelling assumptions for the Madhupur event and illustrate that with reasonable alternate assumptions loss estimates can vary by 50% or more from the mean expected loss.

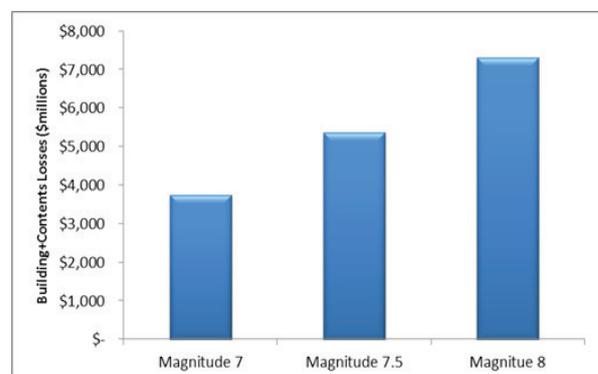
### Alternate Attenuation Equations

Previous results showed losses for the Madhupur event which are the average of the losses calculated using four individual ground motion attenuation equations. This chart below shows losses for each individual attenuation equation. There is approximately a 50% increase in losses in going from the lowest to highest outcome.

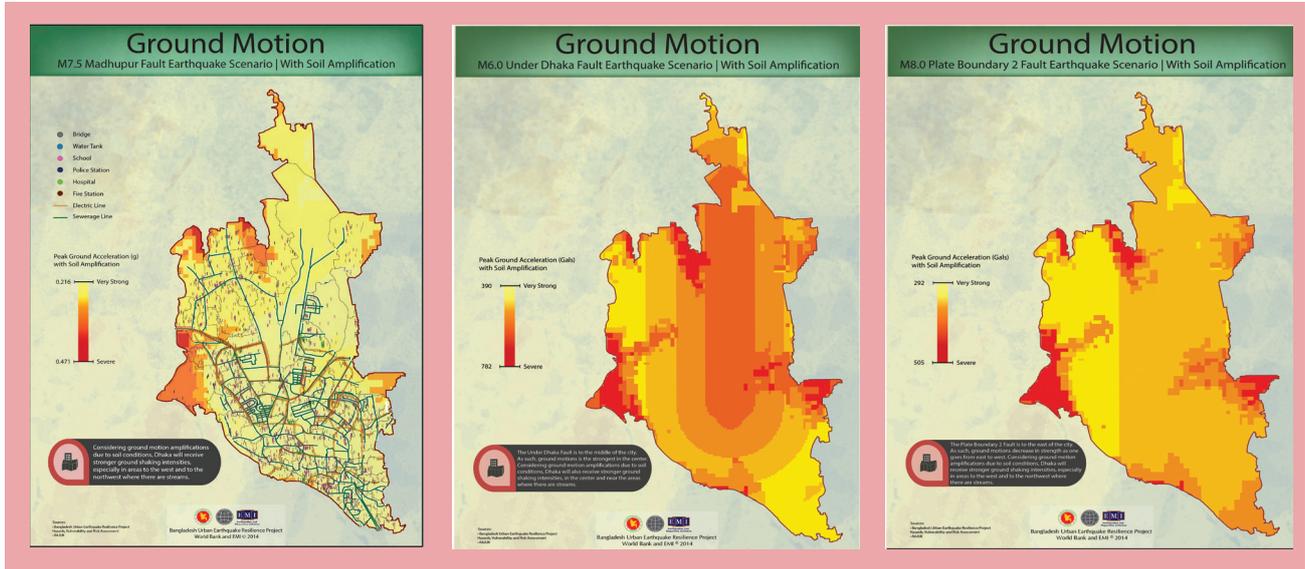


### Alternate Magnitude

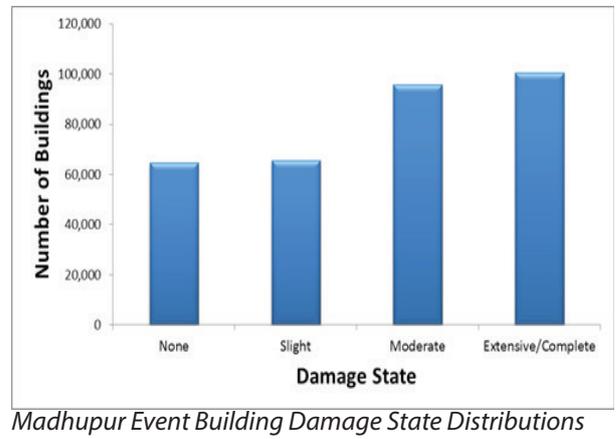
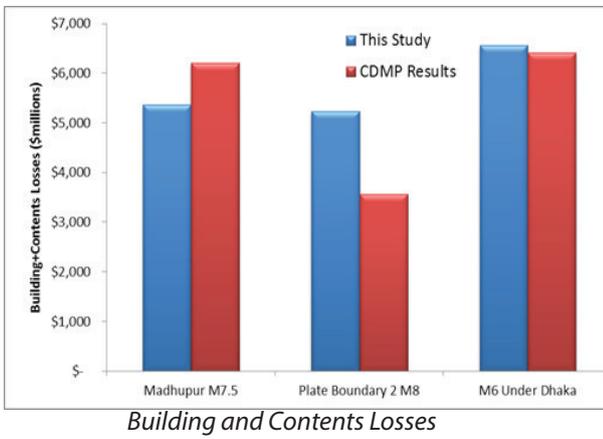
The maximum magnitude of the Madhupur event is estimated to be 7.5. However, there is uncertainty in the estimate given lack of data regarding its potential length and area of rupture. This chart below shows loss results for magnitude 7, 7.5 and 8 events. A magnitude 8 event produces losses approximately twice a magnitude 7 event.



Scenario Ground Motions

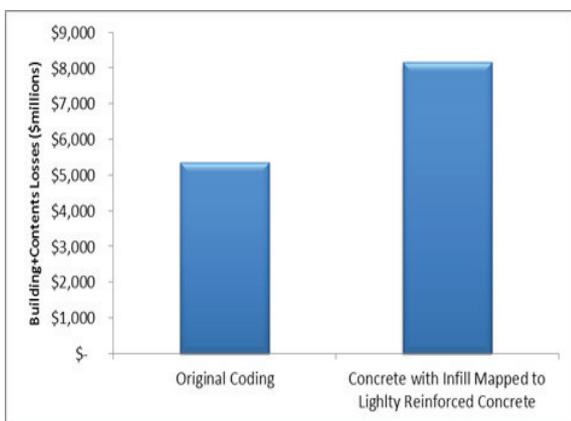


Scenario Building and Contents Losses



### Alternate Vulnerability

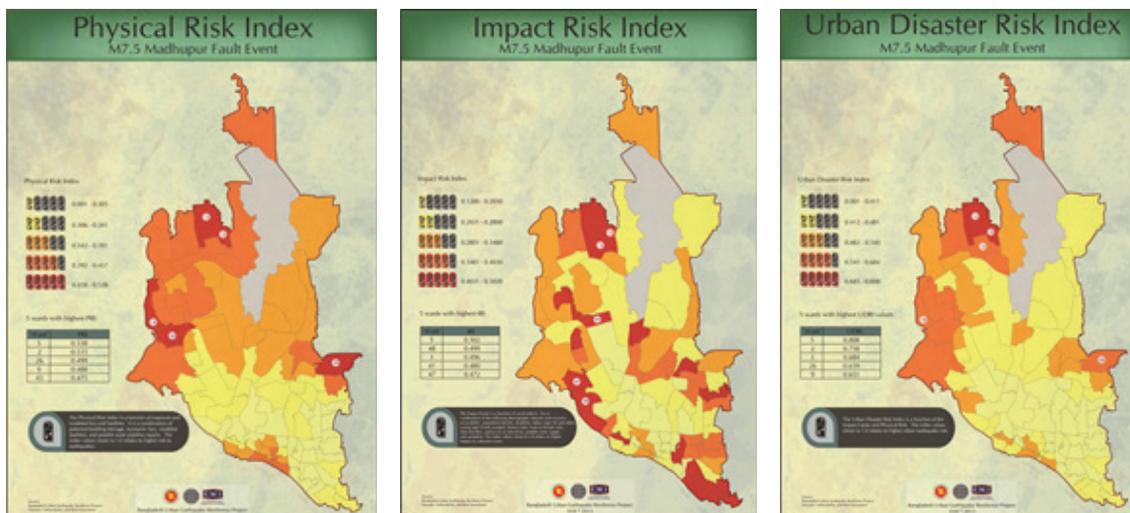
A majority of exposure in Dhaka is coded as reinforced concrete with masonry infill with a lesser amount coded as a more vulnerable lightly reinforced concrete class. Given the lack of past damage experience in Bangladesh there is uncertainty in the derivation of vulnerability curves. In this sensitivity test, all concrete was coded as the more vulnerable lightly reinforced concrete class which results in a 50% increase in losses.



### Urban Disaster Risk Indicators (UDRI)

Risk indicators and “hotspot” analysis was used to identify concentrations of the highest impact areas in order to focus respective disaster planning and decision making on resource allocation and disaster risk reduction investments. The hotspots are based on Wards,

which are the smallest administrative unit relevant in emergency planning, preparedness and policy making. Hotspots are defined by a combination of the expected direct physical damage and losses, and the potential for aggravating impact of the direct damages by the social fragility and coping capacity of the different Wards in Dhaka. These two categories form, respectively, Physical Risk Index (PRI) and the Impact Factor Index (IFI). The Physical Risk Index is a derived based on losses (Building Damage, Fatalities, and Economic Loss) expected from a Magnitude 7.5 event on the Madhupur fault scenario. The selection of impact factors is based on the well accepted definition of social vulnerability as “the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard”. At the same time, the Impact Factor will increase if the capacity to overcome vulnerability in face of hazards is not present. In particular, the Indirect Impact Index (IDI) is derived based on the following indicators: Population Density, Vulnerable Population (Elderly, Very Young, Disabled, Illiterate, Gender Ratio, and Dilapidated Housing), Lack of Access to Services (Electricity, Water, and Sanitation) and Lack of Coping Capacities (Hospitals, Schools and Police Stations). The Urban Disaster Risk Index (UDRI) is simply a combination of the PRI and the IFI by multiplying these two composite indices together.



# Acronyms

BUERP	Bangladesh Urban Earthquake Resilience Project
CDMP	Comprehensive Disaster Management Programme
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
DRRM	Disaster Risk Reduction and Management
DRMMP	Disaster Risk Management Master Plan
EMI	Earthquakes and Megacities Initiative
FG	Focus Group
FGD	Focus Group Discussion
GIS	Geographic Information Systems
GOB	Government of Bangladesh
GSB	Geological Survey of Bangladesh
HVRA	Hazard, Vulnerability and Risk Assessment
ICT	Information and Communications Technology
NGA	Next Generation Attenuation
PGA	Peak Ground Acceleration
URR	Urban Risk Reduction
USGS	United States Geological Survey

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# About the Document

This document is submitted in compliance with EMI's contractual obligations to the World Bank for the Bangladesh Urban Earthquake Resilience Project. The Guidebook summarizes the earthquake hazard, vulnerabilities and risk studies relevant to Dhaka, and explains the methodology for interpreting the outcomes of the risk assessment studies and their applications in various developmental processes and in disaster risk reduction planning. The Dhaka Earthquake Risk Guidebook will be a companion to the Dhaka Risk Atlas. The combined volumes represent a single reference on hazards, vulnerability and risks for Dhaka.

The HVRA analyses undertaken for Dhaka by this project rely significantly on previous studies such as the Comprehensive Disaster Management Program (CDMP) and on published research on Bangladesh earthquake hazards and risks. In particular, the exposure data (i.e., quantification, characterization and spatial distribution of the assets at risk in Dhaka) was provided by the World Bank and was originally developed by the CDMP. The exposure data was used "as is" and no attempt was made to check its accuracy or completeness.

The scientific knowledge on earthquake hazards and in particular the geomorphology, tectonic, seismicity and the relationship between the scientific parameters that are needed for the analytical modeling of earthquake hazards are incomplete. Thus, many parameters are highly uncertain. These include the actual location of the traces of the faults, and most specifically the Madhuapur Fault, the maximum magnitudes assigned to these faults and the recurrence relationships that correlate describe frequency and severity of earthquake events on the faults are not known with certainty. Similarly, knowledge on soil characteristics in Dhaka is incomplete as is the knowledge on the

vulnerability of buildings. Thus, results of the HVRA, while using the best available science, should be interpreted within this context. More research and data are needed to further understand and quantify the distribution of earthquake risk in Dhaka. Nonetheless, the current science and the outcome from the HVRA constitute a solid body of information for the development of disaster risk reduction plans and investments, and for raising awareness and improving preparedness.

The general approach to the assessment is participatory, with the project team working closely with the members of the Scientific Consortium and HVRA Focus Group (FG) to refine and validate the assessment methodology, analysis procedures and findings. The participatory process has several inherent goals: a) Reach consensus among local experts and specialists that the best scientific data and methodologies have been used in the study; b) to share information in order to identify gaps in data and knowledge; c) provide a forum for discussions on the earthquake hazards, vulnerabilities and risks to Dhaka and effectively communicate the HVRA outcomes; and define approaches to fill in the key knowledge gaps, to guide future studies and research.

## What is the purpose of the Guidebook?

This Guidebook is intended to serve as a reference that explains the relevance, methodology, process, and findings of the Earthquake Hazard, Vulnerability and Risk Assessment (HVRA) conducted in Dhaka as part of the **Bangladesh Urban Earthquake Resilience Project (BUERP)**. It provides an example of a framework for undertaking a HVRA in the context of urban disaster risk

reduction (DRR). The elements of this framework may be followed for similar assessments in other cities in Bangladesh. More specifically, the Guidebook objectives are twofold:

- Explain the HVRA concepts, methodology and process that national expert and specialists can follow to undertake similar studies in other cities in Bangladesh
- Educate the non-experts but informed professionals and public officials on the science behind HVRA, how it was undertaken in Dhaka, and how the findings and outcomes can be used in planning disaster risk reduction strategies and plans.

and descriptions of the stages and tools used in the process, as well as the presentation of actual project activities carried out in Dhaka.

## Who should use the Guidebook?

The primary audience of the Guidebook are experts and specialists working on hazard, risk, and vulnerability assessments, emergency managers, government officials, private sector and community representatives involved in and concerned with urban disaster risk management (DRM), and other practitioners and researchers in DRM and related fields in Dhaka, particularly the Focus Groups, Advisory Committee and Scientific Consortium of the BUERP.

## How will the Guidebook benefit the reader?

The Guidebook can be used to understand the **methodology, process, and findings** of a city-level HVRA, specifically the investigations undertaken as part of the BUERP. It is intended as a reference for stakeholders in Dhaka that will help them to better appreciate the significance of HVRA as the foundation of urban DRM planning, and gain basic working knowledge on the different stages of HVRA implementation, through the explanations

# 1 Introduction

## 1.1 What elements contribute to a city's disaster risk?

Disaster risk is often expressed as a function of the interaction between **hazard** and **vulnerability**. The first component considers how probable the occurrence of a hazard event such as an earthquake is, the possible extent of its impact, and how severe that impact will be, while the second component looks into what elements are exposed to the hazard, how susceptible they are to losses, and whether these elements have the capability to withstand the negative impact of the hazard event.<sup>1</sup>

## 1.2 How does HVRA contribute to the management of disaster risk?

Hazard, vulnerability and risk assessment (HVRA) is the process of collecting and analyzing information about the nature, likelihood and severity of disaster risks.<sup>2</sup> This type of assessment provides disaster managers with the information and tools for making decisions on how to reduce these risks, specifically on what hazards to focus attention on and the necessary approaches for mitigating the impacts of hazard events. These assessments can also be used in estimating the probable impact of disasters, and identifying who would be most affected and what can be done to assist them in the post-disaster recovery and rehabilitation phases.<sup>3</sup>

<sup>1</sup> Khazai, Bijan. (2012). *Basic Concepts of Risk Analysis. Natural Disaster Risk Management Program. Global Facility for Disaster Reduction and Recovery. Transcript.*

<sup>2</sup> Khazai, 2012.

<sup>3</sup> Khazai, 2012.

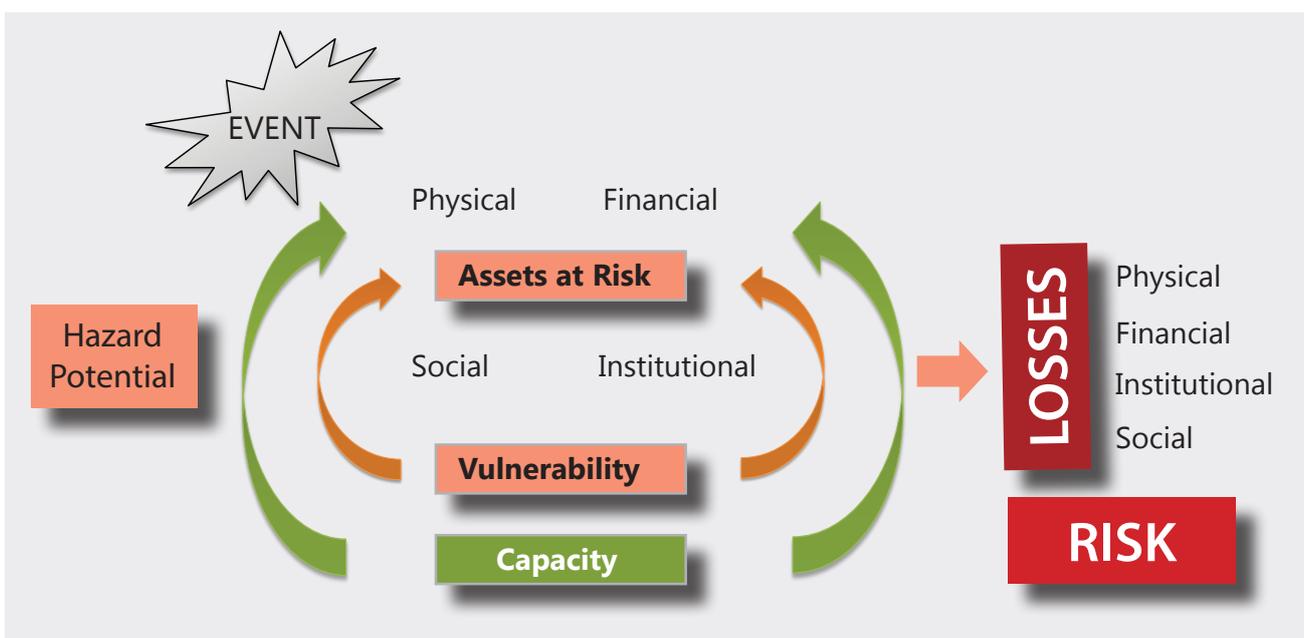


Figure 1. Interaction Between Hazard, Vulnerability and Exposure to Determine Risk

By helping emergency managers, urban planners and public policymakers understand the impact of natural hazards; HVRA can also be a useful tool for developing emergency preparedness plans and mitigating disaster risk. The results of the assessment can be used to model the effects of different mitigation techniques, which can then be incorporated into preparedness programs and urban development plans.<sup>4</sup>

### 1.3 How can HVRA support DRM planning?

HVRA can be considered the foundation of disaster risk management because it provides the parameters that can guide policymakers and emergency managers in developing strategies and operational plans to mitigate and prepare for disaster risks. HVRA enables stakeholders to understand:

- ✓ Potential human (casualty, displaced people) and material losses (damages and economic losses), functional impacts (downtime) and their spatial and sectoral distributions;
- ✓ Impact on critical facilities and functions;
- ✓ Determination of high risk areas or “hotspots”;
- ✓ Determination of evacuation roads and potential for fires, explosions and hazardous material release; and Assessment of disaster “demands” versus the available “resources.”

### 1.4 What is the project approach to DRM planning?

The BUERP seeks to promote the mainstreaming of DRR in Dhaka. Mainstreaming refers to the process of incorporating the practice of risk management within the governance and operations of public and private institutions by developing and modifying laws, policies, institutional arrangements, plans, programs and projects.

By giving a clear picture of Dhaka’s risk profile and providing insights on the development systems and processes into which risk management can be incorporated, HVRA supports the integration of urban risk reduction (URR) in the key functions

#### When is a hazard event considered a disaster?

A disaster occurs when the daily life within a community is seriously disrupted because its members are unable to cope with the human, material, and economic or environmental losses and impacts brought about by a natural or man-made hazard.

Disaster impacts may include loss of life, injury, disease, damage to property, destruction of assets, loss of essential services, social and economic disruption and environmental degradation.

(Source: UNISDR Terminology, 2009)

<sup>4</sup> Bendimerad, Fouad. (2001). *Loss estimation: a powerful tool for risk assessment and mitigation. Soil Dynamics and Earthquake Engineering*, 21, 467-472.

that public and private institutions undertake, such as land use and urban development planning, construction and building licensing, environmental management, social welfare, and other services that they provide and regulate.

This approach follows the Disaster Risk Management Master Plan (DRMMP) model developed by EMI and tested in different megacities around the world such as Istanbul, Metro Manila, Kathmandu, and Mumbai. The DRMMP is an analytical process that guides stakeholders in the development of strategies, policies, actions and processes for mainstreaming disaster risk reduction at the local level through a series of participatory planning activities. It enables city officials and other key stakeholders to:

**UNDERSTAND** their risks considering the vulnerabilities to hazards and the capacities to withstand these hazards;  
**EVALUATE** the physical and socio-economic impacts of these hazards in terms of damages, losses and downtime;  
**ACQUIRE** the competency to plan disaster risk reduction activities and investments and effectively manage emergencies;  
**DETERMINE** a series of options to reduce the risk and define their priorities and implementation processes; and  
**DEVELOP** a coherent approach to managing the overall risk.

The DRMMP is guided by the following principles:

1. ***The process must be participatory*** to ensure that the stakeholders are primarily responsible for the development of project outputs and exercise ownership over the project.
2. ***A rational division of authority and responsibility must be recognized*** by all the stakeholders, as explained in the following rules:
  - a. Implementation should take place at the local level; i.e., the greater the decentralization process, the more gain in efficiency.
  - b. The authority for policy, regulation, control, resource allocation and oversight rest with the central government.
  - c. Government (central and local) must open the door to the participation of civil society, which collectively groups all the active agents of society.
3. ***Policies, decisions and actions must be scientifically based***, meaning that the sound understanding of the disaster risks through scientific information that is validated, communicated, and translated into parameters is what will guide policy and inform decisions and actions.

### Significance of Mainstreaming In DRM

Mainstreaming is a critical element of the management of disaster risk because it ultimately assigns clear roles and responsibilities. This builds efficiency and accountability, which are the core ingredients to disaster risk reduction. The extent to which risk reduction has been incorporated into development planning and processes, and aligned with the existing context of local community needs and resources, has a direct influence on the resilience of cities and their residents to the impacts of natural disasters.

# 2 HVRA Methodology

## 2.1 What approaches are used in HVRA?

### A. General Approach

The aim of the HVRA component of the BUERP is to develop an understanding of the impact of earthquakes in Dhaka by assessing the location and magnitude of potential earthquakes, the resulting severity of ground motion and ground failure, and the consequent physical and socio-economic losses. Figure 2 below shows the general methodology for undertaking a risk assessment study.<sup>5</sup> In the following the key steps in the analysis will be explained.

### B. Data Collection and Assessment

The HVRA for Dhaka requires the collection of two general sets of input data: seismic hazard data and infrastructure inventory data. Seismic hazard data provides the information on the geology, geomorphology, seismo-tectonic, seismicity, soil, site conditions, and earthquake energy attenuation characteristics. This information is used to compute the potential for ground motion and ground failure and their related probabilities at a specific site. These elements quantify the “demand”, which is the common quantity used to represent the earthquake hazard. It can be expressed in terms of spectral acceleration, spectral displacement and/or spectral velocity. Infrastructure inventory data provides information on the built environment, including building stock, transportation system, lifeline (utilities) system and critical facilities. The inventory is used to establish a classification of the built environment

<sup>5</sup> Risk assessment studies are also referred to as loss estimation studies

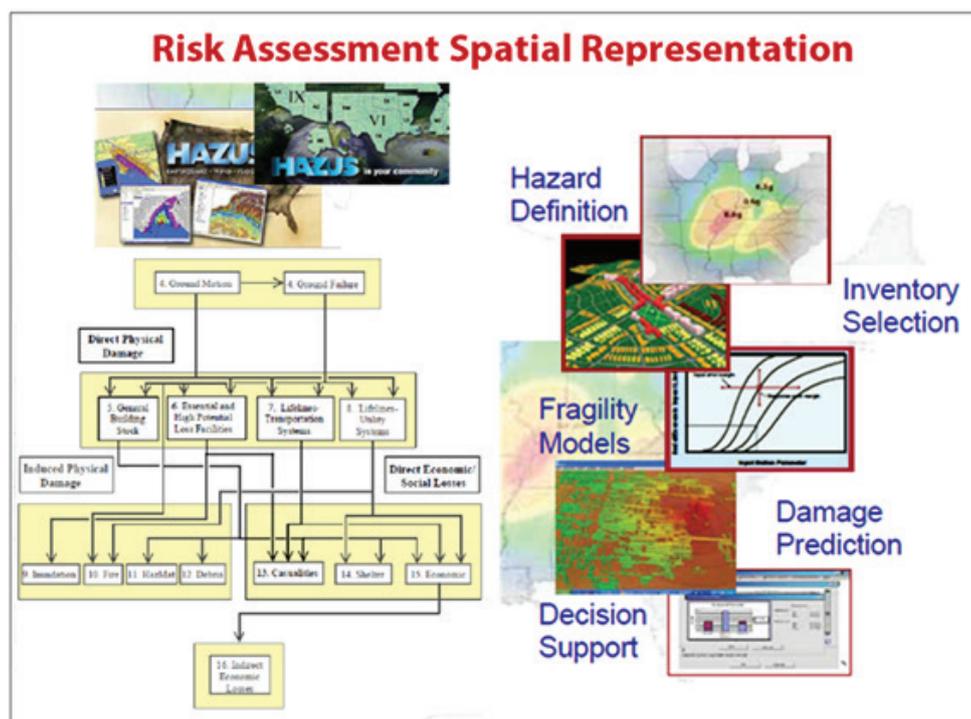


Figure 2. Analytical Methodology and Component of HVRA Analysis (from HAZUS)

Table 1. Data Requirements for Earthquake Risk Assessment

Seismic Source Characterization	Ground Motion Attenuation, Soil and Site Characteristics	Exposure Data	Vulnerability
Tectonic Setting	Geology	Population Demographics	Damage and Loss footprints of past events
Historical earthquake catalog	Surficial Geology	Building Inventory	Vulnerability relationship for similar construction in other regions
Source characteristics (i.e., segmentation, Max magnitude, Recurrence Rates)	Soil Characteristics	Building Characteristics (Age, Construction material, Structural System, Height, etc.)	Fire following Potential
	Attenuation Characteristics	Critical Facilities (hospitals, emergency centers, police and fire stations, key public buildings)	Hazardous Material potential impacts
	Recorded Ground Motions	High Loss Facilities (e.g. schools, stadiums, petroleum and gas storage)	
	Past event intensity distributions	Transportation System (roads, bridges, ports, airports, etc.)	
	Liquefaction Potential	Water, Wastewater and Drainage Systems	
	Landslide Potential	Power Systems (generation, transmission, distribution)	
		Communication System	
		Contingent Liabilities	

into engineering construction classes. The engineering characteristics of a construction class determine its “capacity” in terms of earthquake demand, represented by a building’s lateral load resistance as a function of lateral displacement.<sup>6</sup> Table 1 identifies the specific data that is required for an earthquake risk assessment.

For this project, the needed data was primarily collected from a desk review of the study undertaken by the Comprehensive Disaster

Management Program (CDMP), as well as other available scientific literature on earthquakes, particularly those that contain loss estimates and other disaster data.

The functional relationship that provides the probability to reach or exceed a damage level as a function of the earthquake severity is referred to as the “fragility function.” Five damage states are considered: None, Slight, Moderate, Extensive and Complete. Structural and non-structural fragility functions are evaluated for spectral displacement and spectral acceleration defined

<sup>6</sup> Bendimerad, 2001.

by the intersection of the capacity and demand curves. The intersection of the demand curve and capacity curve determines the damage potential for the construction class.<sup>7</sup> A sample fragility function is illustrated in Figure 3.

The inventory data is structured into two classifications: Occupancy and Construction. Occupancy provides information on the use and function of the built environment within a geographic unit (e.g. housing, school, retail, commercial, etc.). Construction classification provides a distribution of the inventory of the built environment into engineering construction classes of similar damage potential (e.g. wood, masonry, concrete, steel, etc.). The inventory needs to be structured such that an analysis can be done with a minimum level of data, with a built-in flexibility to allow for the incorporation of improved data with time. A tiered classification of the inventory is well suited for such a purpose.

In a tiered classification, each tier provides a different layer of resolution in data. For example, the first tier of data may be limited to a division of the inventory into four classifications: Residential, Commercial, Industrial and Critical. The second tier would provide more segregation within each of these categories. The first tier represents a

<sup>7</sup> Bendimerad, 2001.

minimum level of data resolution and allows for a first order approximation of the potential losses with minimum reliance on experts. The level of resolution in the analysis depends on the quality of the data. An analysis based on Tier 1 will have higher uncertainty than an analysis based on data from a higher tier.<sup>8</sup>

The redistribution of the inventory into construction classes follows the same principal of tiered classification and hierarchical relationships between tiers. The most natural hierarchical relationship relates to the material of construction. The primary tier consists of the basic materials used in construction around the world such as: stone and rubble, masonry, wood, concrete, and steel. Each tier is then subdivided into secondary tiers and if necessary into tertiary tiers providing more and more detailed information on the construction characteristics.<sup>9</sup>

The lifeline systems include power (electricity, oil, steam and gas), water system, wastewater and communication. The transportation systems include highways, roads, railroads, ports, airports, and other transportation. In general, each component has a different fragility or probability of failure given a certain amount

<sup>8</sup> Bendimerad, 2001.

<sup>9</sup> Bendimerad, 2001.

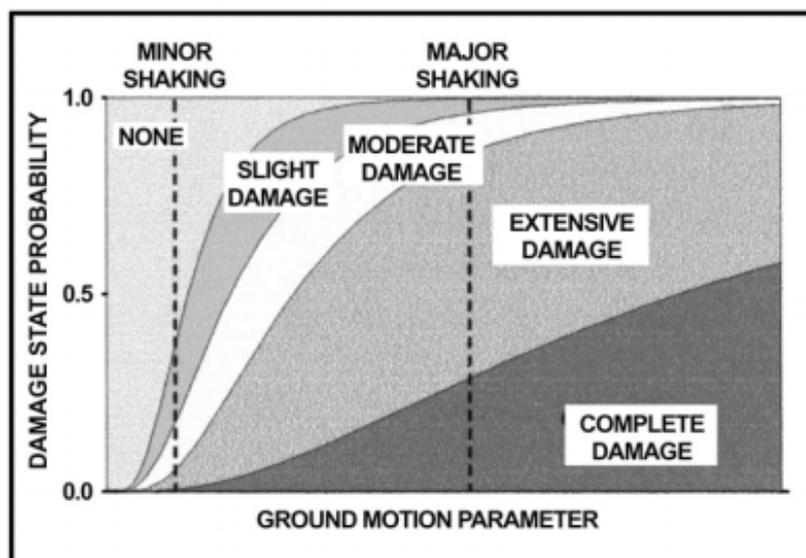


Figure 3. Example of Fragility Function

Table 2. Sample Occupancy Classification

First tier	Second tier	First tier	Second tier	Third tier
●Residential	Single family Multi-family Institutional	●Transportation	Land transport	Highway Bridge Roads
●Commercial	Retail trade Light manufacturing Professional		Marine transport	Ports Cranes
			Air transport	Airports
●Industrial	Heavy fabrication Petroleum Food and drug	●Utilities	Water systems	Pipes Pumping stations Treatment plants
			Power systems	Power plants
●Critical facilities	Hospitals Emergency centers Schools			Substations Transmission Distribution
			Gas systems	

of earthquake demand. Often lifeline systems are sub-characterized by a number of primary components (e.g. highway systems include bridges) which typically have different sizes (e.g. long-span bridges) and different levels of seismic capacity (e.g. seismically designed long-span bridges).<sup>10</sup>

## 2.2 Risk Assessment Knowledge, Validation and Benchmarking

Before performing the analysis, the data is audited for completeness and consistency, and checked against industry benchmarks. The examination of the earthquake risk assessment done by the CDMP is the starting point for the analysis of the collected data. The scientific basis, data and assumptions behind the CDMP study are examined, and sensitivity analyses are carried out to better understand the key drivers of variability and uncertainty in estimated potential losses.

<sup>10</sup> Bendimerad, 2001.

The CAPRA<sup>11</sup> model developed by the World Bank is used for the sensitivity analyses and to compare results with the CDMP findings. The working assumptions and methodologies behind CAPRA are also examined and shared with the Focus Group members and other specialists, in order for them to gain a better understanding of the use of the model.

A validation and benchmarking exercise is then undertaken with the members of the Scientific Consortium and HVRA Focus Group in order to develop scientific consensus and acceptability by users and facilitate risk-based decision making. Gaps in knowledge are identified and recommendations for improvement in terms of future risk assessment studies are provided.

<sup>11</sup> CAPRA is a Disaster Risk Information Platform for use in decision-making that is based on a unified methodology and tools for evaluating and expressing disaster risk. The CAPRA initiative started in January 2008, as a partnership between Center for Coordination of National Disaster Prevention in Central America (CEPRENAC), the UN International Strategy for Disaster Reduction (ISDR), the Inter-American Development (IADB) and the World Bank as a means to raise awareness among countries in Central America by providing them with a set of tools that would let them better understand the risk of adverse natural events.

An extensive earthquake risk analyses was performed as part of the Comprehensive Disaster Management Program. Loss analyses were performed in HAZUS, a risk analysis software program developed in the United States, sponsored by FEMA.

On the other hand, the BUERP utilized CAPRA, a suite of multi-peril risk analysis software tools, for the core hazard & vulnerability analyses. The CAPRA analyses were also supplemented with additional calculations.

## 2.3 Risk Communication and Stakeholders' Participation

Risk assessment methodologies are highly empirical and the parameters carry a large uncertainty. There is limited scientific knowledge regarding earthquake hazards in Bangladesh. It is thus important to undertake consultations with both the experts and the potential users of the HVRA outcomes to ensure that:

1. There is consensus among the experts that the best available knowledge is used for the analysis
2. The outcome of the study are well understood by the potential users for the purpose of future applications

In this context the project has two avenues for accomplishing these goals:

The primary mechanism for reaching scientific consensus on the HVRA parameters and the scientific considerations undertaken in the modeling of earthquake hazards, vulnerability and risk is the **Scientific Consortium (SC)**. This is a small group of renowned local experts in risk assessment, earthquake engineering, and geology/geophysics, as well as in other fields addressed by the project, mainly land use and regional planning, disaster risk management, law and business administration, environmental management, and other closely related fields. The members of the SC are selected on the basis of their credentials

and focus their activities on reviewing the HVRA methodology, validating the analysis and findings, and advising on other scientific and technical matters. The main role of the SC is to review the approach and parameters used and provide guidance to the HVRA team on potential improvements and other scientific considerations. The objective is to ensure that there is consensus among the scientific community that the best available science has been used in the study and that the approaches and methodologies are scientifically robust. The workshops and meetings with the SC are also an opportunity to improve knowledge and skills in HVRA as the project team has significant expertise and global knowledge in the topic.

Another forum for stakeholder engagement is the HVRA Focus Group. The role of the HVRA Focus Group is more oriented towards capacity building and risk communication. The group is composed of representatives from key local agencies and international organizations, as well as individual researchers and practitioners who have relevant knowledge or experience in terms of data on earthquake hazard, vulnerability, exposure and loss in Dhaka, who have been identified in the preliminary scoping activities and consultations. Representing their institutions and organizations, the FG members support the HVRA through data collection and validation. In addition, the group provides a venue to stimulate discussion in order to develop a common understanding of Dhaka's earthquake parameters, build consensus on the approach for investigating how these parameters contribute to disaster risk in the city, and validate the assumptions and findings of the HVRA investigation. The group provides the opportunity for stakeholders to enhance their competencies in risk assessment throughout the course of the project and ensure sustainability of DRM practice in the long run.

In addition to the Scientific Consortium and the Focus Group, the **Advisory Committee (AC)** also helps to ensure collective contribution and teamwork among the project team and

stakeholders. It is comprised of policy and decision-makers from various government and non-government institutions. Designated by their respective institutions, the AC members provide overall guidance and oversight, and their meetings serve as a forum for policy-level consultation and engagement consistent with the project's mainstreaming goals.

Several meetings, workshops, and consultations are undertaken during project implementation to accomplish the goals of the participatory process. While the process is guided by the experts, the outcome is controlled by the input and the level of engagement and contribution from the stakeholders. Thus, the validity of the HVRA investigation relies, to a great extent, on the success of the participatory process.

## 3 HVRA Process for Dhaka

### 3.1 What are the stages in the HVRA Process?

The investigation process is composed of four phases, with the outputs of each phase contributing to the accomplishment of the objectives of the succeeding phases. The process is illustrated in Figure 4. The different phases are discussed in more detail in the succeeding sections.

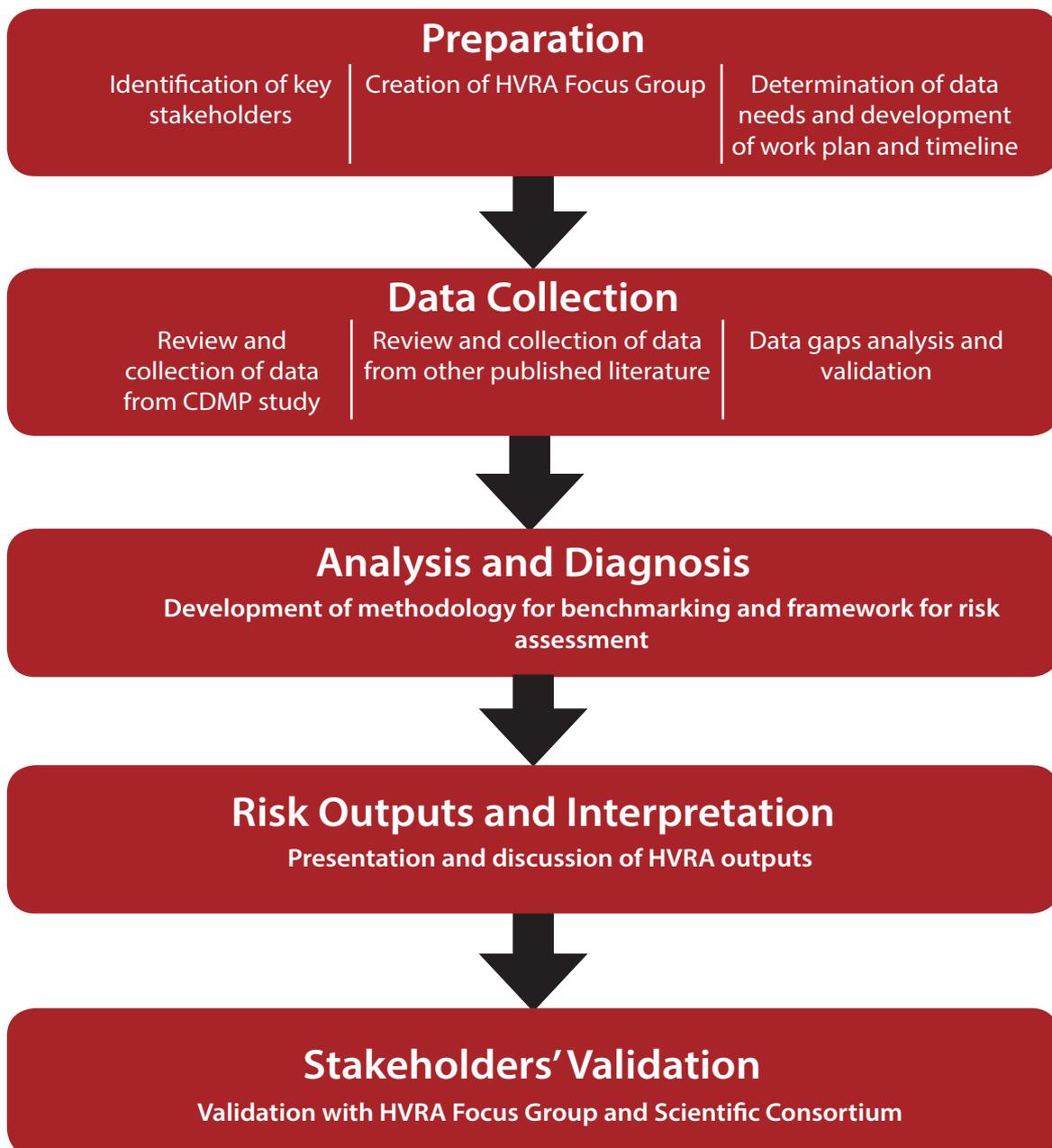


Figure 4. HVRA Investigation Process

## A. Preparation

In the Preparation phase, initial scoping was conducted to identify the key individual and institutional stakeholders. This was accomplished through consultations with international and local experts, and the review of secondary sources of information. The identified experts were invited to form the Scientific Consortium, a small group of selected individuals with significant expertise in fields such as risk assessment, earthquake engineering, and geology/geophysics. The SC is tasked with reviewing the HVRA methodology, validating the analysis and findings, and advising on other scientific and technical matters. Representatives from relevant organizations were also invited to form the HVRA Focus Group. The HVRA FG is composed of representatives from key international and local organizations and agencies, as well as individual researchers and practitioners who have relevant knowledge or experience in terms of data on earthquake hazard, vulnerability, exposure and loss in Dhaka (see **Annex 1**). The group members assist the project team in the determination of data needs. The details of the assessment database and the schedule of investigation activities were also

developed and finalized at this time.

The key outputs of the Preparation phase are:

- Identification of key experts and stakeholders through review of secondary sources and consultations
- Creation of HVRA Focus Group
- Determination of data needs and establishment of assessment database
- Development of investigation work plan and timeline.

## B. Data Collection

In order to perform a complete earthquake risk assessment, the data described in Chapter 2 must be gathered and reviewed.

Exposure:

- Inventory of buildings/contents
- Lifeline exposure
- Population distribution

Hazard:

- Seismic source identification including maximum magnitudes and recurrence relationships

### Example of Preparatory Phase Activities in Dhaka

#### Field Investigation (Nov. 25-29, 2012)

This activity had the following objectives:

- Identify and collect relevant HVRA data;
- Introduce the project to the HVRA Focus Group and get their input on the project plan;
- Meet with individuals and groups who can provide information and guidance to the project;
- Establish a working relationship with local investigator for HVRA and the remainder of the project team;
- Acquire sufficient knowledge on available HVRA data to allow the development of a detailed project plan.

At the conclusion of the Field Investigation, the following results were obtained:

- ✓ Identified possible data sources and developed list of available data;
- ✓ Finalized HVRA work plan.

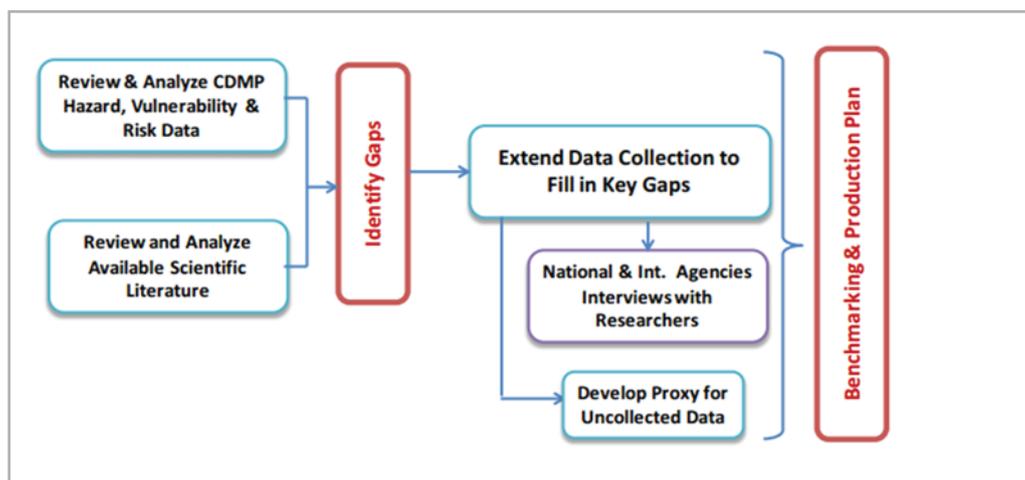


Figure 5. Work Flow for Data Collection Process

- Regional ground motion attenuation relationships
- Soil characteristics including landslide and liquefaction potential

#### Vulnerability:

- Relationships describing the impacts of ground motions on buildings, contents, lifelines
- Casualty estimation

For the BUERP study, particular focus was placed on the review and examination of the data gathered by the CDMP study, due to the significant amount of information on exposure and other relevant scientific data that it contains.

The five primary CDMP reports are as follows:

- Time Predictable Fault Modeling of Bangladesh
- Engineering Geological Mapping of Dhaka, Chittagong and Sylhet City Corporation Area
- Seismic Hazard Assessment of Dhaka, Chittagong and Sylhet City Corporation Area
- Vulnerability Assessment of Dhaka, Chittagong and Sylhet City Corporation Area
- Risk Assessment of Dhaka, Chittagong and Sylhet City Corporation Area.

The scientists who were engaged in the CDMP earthquake loss studies were consulted to make sure that there are no gaps in the project team's

understanding of the analysis and results of the study. Discussions with these scientists were also undertaken to seek their insights and opinions on the uncertainties and other considerations of the study that may need to be reviewed and re-examined. This enabled the project team to clearly define the scope for utilizing and improving the earthquake studies undertaken under the CDMP program, specifically the earthquake loss scenarios for Dhaka.

At the start of the data collection process, two parallel efforts were undertaken, namely: the review of the CDMP study and a review of general scientific literature and other information from relevant earthquake and disaster data depositories. The collected data was analyzed in terms of relevance and catalogued. This inventory facilitated the identification of data gaps.

As illustrated in Figure 5, to fill these gaps, the project team devised a plan for identifying potential sources for the missing data and a strategy for collecting such data, which could be from national agencies (e.g. for exposure data or population data, soil data, etc.), international agencies (e.g., loss data), or interviews and surveys of specialists, researchers, and institutions that are difficult to reach. Proxies were developed for data that is impossible to collect or unreliable. In those cases, studies





the region being analyzed, expert opinion is often used to derive a broad characterization of the building inventory.

A final inventory can be expressed in terms of a table similar Table 3 which shows the percent of buildings by occupancy, construction and number of stories. This is an illustrative example; an actual inventory could be more or less detailed. For example, additional construction and occupancy classes might be included as well as additional attributes such as year of construction. Inventory data such as this should be compiled for each sub-region within a study area where the mix of building inventory varies. For example, the building distribution in city centers is typically skewed towards high-rise buildings compared to the building distribution in suburban and more rural areas.

Distributions such as these can be developed by getting input from professionals familiar with the building stock in the study region such as structural engineers, or performing site surveys of a limited random sample of buildings and extrapolating results to the entire study region. Additionally, the use of aerial imagery, sometimes supplemented by rapid drive by inspections, can be used to develop inventory data when such resources are available. For key essential facilities such as hospitals, and fire and police stations, it often makes sense to gather building specific information even if the general building stock inventory is at a coarser resolution.

The data used to derive Table 3 would take into consideration the total count of buildings and average square footage for each category. In order to calculate financial losses, the square footage numbers need to be converted into monetary terms, this is typically done by assuming a replacement value per unit floor area that will vary by occupancy and constructions class. Unless detailed contents information is available, contents values are typically calculated as a percentage of building value, the percentage varying by occupancy.

### *Inventory of Lifelines*

As discussed in Chapter 2, lifelines consist of systems that help keep a region running:

- Transportation (roadways, railways, bus, ports, airports)
- Water Supply
- Waste Water
- Natural Gas
- Electric Power
- Communication
- Oil

Functionality of lifelines is critical for regional recovery following a significant earthquake event. Typically this information must be obtained directly from the local government organization or private entity responsible for each lifeline.

For distribution systems such as water, information should be gathered for both key individual components/structures such as treatment plants and pumping stations as well as the pipeline distribution system. For distribution systems, the linear kilometer of pipeline (or roadway for a transportation system) is quantified at some geographic unit. This distribution detail must often be extracted from GIS data.

### *Population Distribution*

Population data is usually the easiest exposure information to obtain, available from government census taking organizations and available at relatively fine resolution.

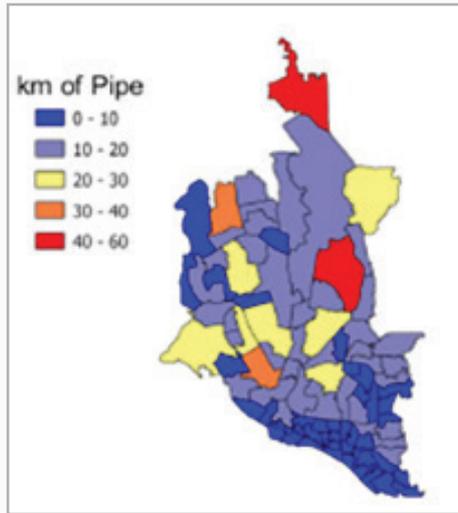
## **Hazard Data**

### *Seismic Sources*

The first step in modeling seismic hazard for an earthquake risk analysis is defining seismic sources including the location and type of fault (e.g. strike slip or subduction), the maximum magnitude of the faults, and recurrence

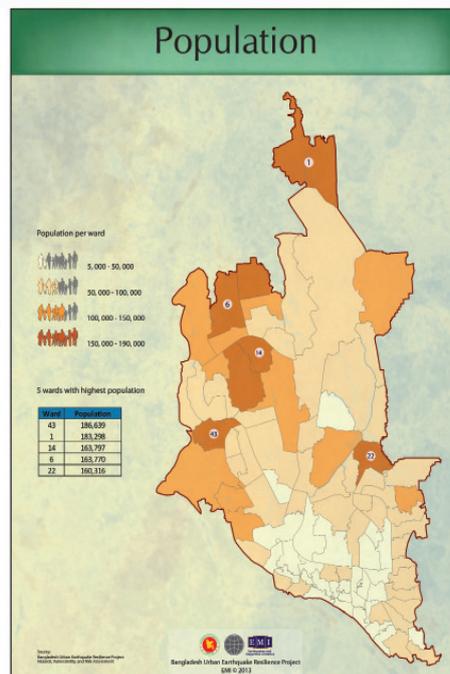
### Lifeline Inventory in Dhaka

The BUERP study analyzed lifeline exposure for potable water, waste water, and natural gas pipelines as well as roads and highways. The inventory data was extracted from the CDMP vulnerability report which describes the development of inventory data for these and additional lifelines. The map below shows kilometer of potable water lifelines for each ward within Dhaka.



### Population Distribution in Dhaka

The map below shows the population distribution within Dhaka at the Ward level. This data is also available at a cluster resolution from the CDMP report which was used in the risk analysis.



parameters. Earthquake risk assessments have been performed for most regions of the world by government and academic institutions and in some cases private entities. Reviewing the studies that have been previously performed is typically the initial step in setting up a seismic model. Examples of broad efforts to develop earthquake models includes the Global Seismic Hazard Assessment Program (GSHAP) and the currently ongoing Global Earthquake Model (GEM) project. Research by local academic institutions is also often a good source of information.

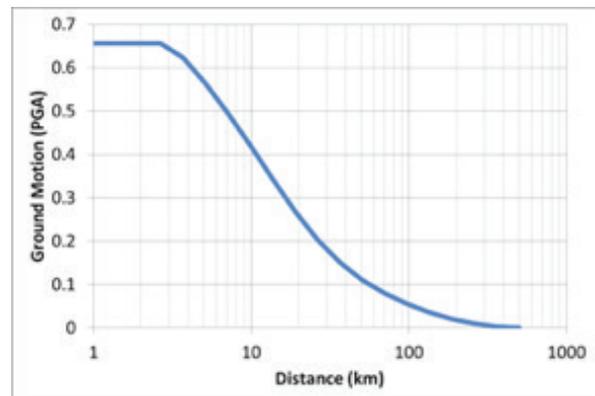
In cases where there is not a suitable or up to date seismic source model, it is necessary to review a catalog of past earthquake events and construct a new model, the details of which are beyond the scope of this document. Additionally, it is often necessary to refine a previously developed seismic model to reflect up to date research and/or additional local knowledge.

A key decision on how the seismic source model will be developed is whether the risk study will focus on specific individual events (a deterministic analysis) or alternatively will attempt to model all events of all magnitudes that could possibly impact the study region (a probabilistic analysis). In the case of a deterministic analysis, the source model can concentrate on a few sources that have in the past or could in the future produce significant ground motions in the study region. Often, the estimated maximum magnitudes will only be considered in the study, those magnitudes based the size of past events on each source and/or the fault size and geometry. A probabilistic analysis is more detailed and requires the estimation of return periods for all potential magnitudes on a fault source as well the possibility of earthquakes occurring in places where there are no known sources, referred to as background sources. The seismicity for background sources is based on geographically smoothing occurrence rates of past earthquakes.

### Ground Motion Attenuation

After the seismic sources to be analyzed are determined, a ground motion attenuation relationship must be assigned to each source. Ground motion attenuation equations relate the geographic distribution of ground motion intensity to the magnitude and type of earthquake fault mechanism as illustrated in the chart below. The ground motion parameter can take many forms such as Modified Mercalli Intensity (MMI), peak ground acceleration, and spectral acceleration. The ground motion parameter is an input into the vulnerability relationship, discussed below. Most current vulnerability relationships use spectral acceleration as an input parameter for building structures in order to better relate the estimated ground motion frequency to the frequency of the buildings being analyzed.

Ground Motion Attenuation Relationship for a Specific Magnitude



The rate at which ground motions attenuate away from a source varies greatly, largely depending on the nature and age of the earth's crust. A extreme example of the differences that can occur can be seen when comparing attenuation of past events in the central and western United States as illustrated below in map produced by the USGS comparing the 1994 Northridge earthquake in California and a central US earthquake in 1895.

### Earthquake History of Dhaka

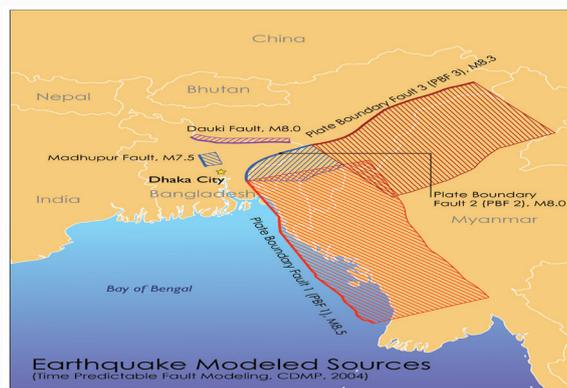
Before developing an earthquake model, it is useful to review the past earthquake history of the study region in order to ascertain the types of events that have occurred in the past and their impacts. In the case of Dhaka, a very informative paper titled “Earthquakes of Dhaka” by Akhter provides a summary of historic events. The map below shows the location of past events and the resulting intensity in Dhaka based upon the Akhter paper.

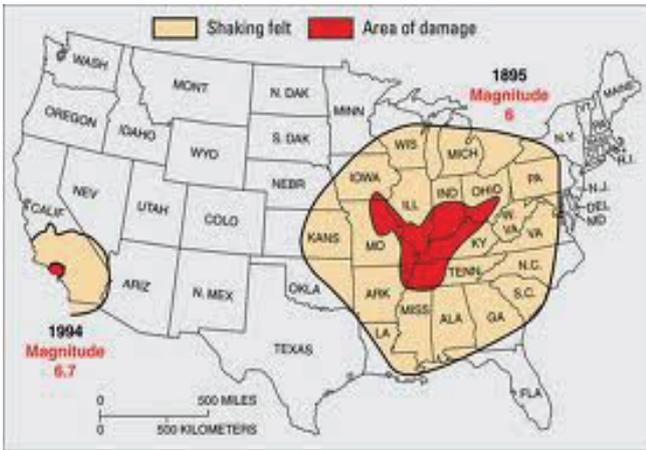


### Seismic Source Model for Dhaka

The seismic source model for the BUERP study utilized the information and model developed as part of the CDMP effort. Details of the seismic source model development effort are provided in the document titled “Time Predictable Fault Modeling of Bangladesh”. That study identified five sources of most interest for the study region which included Dhaka, Chittagong, and Sylhet. These sources are summarized in the table and map below.

Source	Estimated Maximum Magnitude	Last Significant Event
Madhupur Fault	7.5	1885 M7.0
Dauki Fault	8.0	1897 Great Assam Earthquake
Plate Boundary Fault 1	8.5	1762
Plate Boundary Fault 2	8.0	Before 16th century
Plate Boundary Fault 3	8.3	Before 16th century



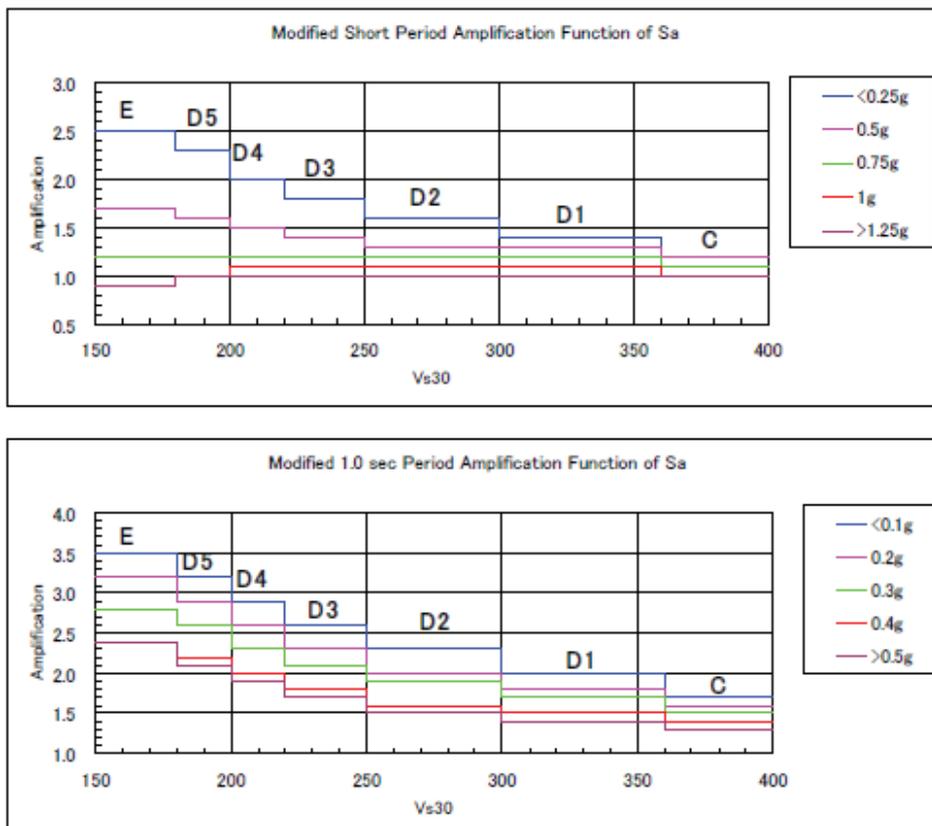


When selecting ground motion attenuation equations for a risk study, it is best to utilize relationships that are based on past ground motion recordings in the region of interest. However, given that regional ground motion recordings are often not available, especially for large earthquakes such as in Bangladesh, it is necessary to rely on relationships based on events in other regions of the world.

### Soil Characterization

The attenuation equations described in the prior section estimate ground motion for a specific soil type (e.g. rock or soil). In reality, soil conditions will most often vary across a study region with softer soils amplifying ground motions. In order to account for local surficial soil conditions, soil types must be characterized across the study region. Most often, the source of this information will be governmental geological agencies. If data is lacking or incomplete it may be necessary to gather borehole data across the region and/or consult with local geologist/engineers. In any case, it is beneficial to consult with local experts when determining how to utilize available geologic information for a seismic risk study.

An example of ground motion amplification factors is shown the figure below, taken from the CDMP seismic hazard analysis report. In this figure, soil type “E” is the softest and amplifies



### Ground Motion Relationships for the BUERP study

In the CDMP risk analyses, ground motions implemented in the HAZUS loss estimation software (described later) were utilized. In the BUERP study, new NGA (Next Generation Attenuation) attenuation equations used in the most recent version of the US earthquake hazards maps were utilized to model the Madhupur and Dauki faults. The following four different NGA attenuation equations were implemented. Results presented later in this Guidebook show losses averaged for the four attenuations as well as losses for each individual attenuation relationship. Given the scarcity of historical large events with instrumental ground motion recordings, reviewing losses utilizing different attenuation equations sheds light on the uncertainty associated with the modeling of ground motion attenuation and the impacts those uncertainties can have on losses.

- AS08: Abrahamson N. and W. Silva (2008)
- BA08: Boore D. M. and G. M. Atkinson (2008)
- CB08: Campbell K. W. and Y. Bozorgnia (2008)
- CY08: Chiou B. S.-J. and R. R. Youngs (2008)

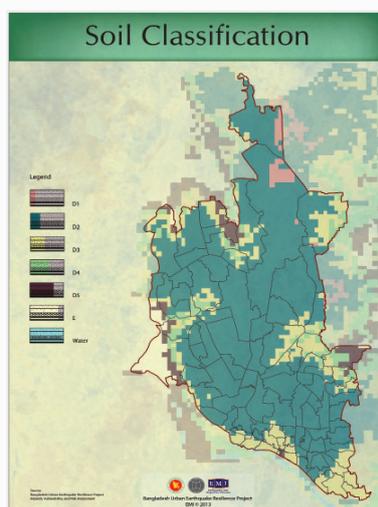
In the BUERP study, for the Plate Boundary sources, the following subduction source specific attenuation equations were utilized.

- Youngs and others (1997)
- Atkinson and Boore (2003)
- Zhao and others (2006)

### Soil Characterization for Dhaka

The BUERP study utilized the detailed geological map developed as part of the CDMP study. That work started with a geomorphic survey carried out by the Geological Survey of Bangladesh. In addition, borehole data was collected to further refine the soil classifications. A great deal of detail can be found in the CDMP report titled "Engineering Geological Mapping of Dhaka, Chittagong and Sylhet City Corporation Area of Bangladesh".

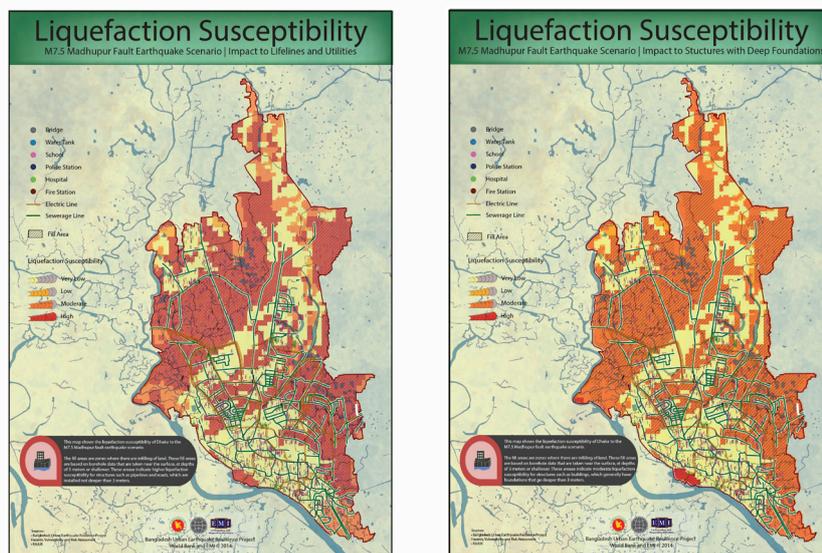
The figure below shows soil classifications in the Dhaka area. Soil classes range from D1 (stiffest) to E (softest). Ground motions will be amplified more on the softer soils.



### Liquefaction Characterization for Dhaka

As described above for soil classification, the BUERP study utilized the liquefaction susceptibility data from the CDMP study, however, one significant change was made. The CDMP liquefaction susceptibility map identified a significant area of Dhaka as fill with very high liquefaction potential. Borehole data indicate the fill is mostly surficial in nature (<3 meters) and likely placed in low-lying areas as the city expanded. In the BUERP study, these areas were classified as having moderate liquefaction potential for building analyses (most building foundations are likely below the fill) and high liquefaction potential for buried utility lifelines. Additional study into the extent and potential impacts of the fill areas in an earthquake are warranted.

The figure below shows the liquefaction susceptibility map for the Dhaka region.



ground motion the most while soil type “C” is the stiffest, amplifying ground motions the least. As can be seen in the figure, the amplification factor is a function of the soil class, the intensity of rock ground motion, and period.

In addition to characterizing the soil amplification characteristics of soil, it is important to ascertain the potential of soils to fail when subject to strong ground shaking. The two most common types of failures that have occurred in past earthquakes are liquefaction and landslide. Liquefaction occurs when saturated or partially saturated soil substantially loses strength and stiffness when subject to strong ground motion. This most often occurs with loose sandy soils. When this occurs, the soil is no longer able to support loads, such as building foundations, and extensive structural damage can occur. Additionally, the settlement

and/or spreading of soils can damage buried pipelines. In the case of landslides, unstable soils on hillsides can lose strength and move downward during an earthquake.

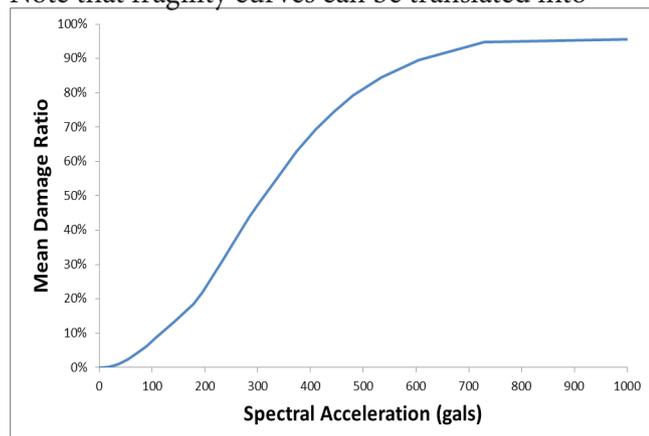
Liquefaction and landslide potential are typically incorporated in a seismic risk study by creating liquefaction/landslide susceptibility maps. Development of these maps requires detailed information on the local properties of soil. Over a large region it is often necessary to make simplifications when assigning liquefaction and landslide potential. For example, in the case of liquefaction, assigning susceptibility based on surficial geological characteristics and general assumptions related to the water table. In order to develop a more detailed susceptibility map, local geological information such as borehole data can be used but typically such information is only available at individual sites.

## Vulnerability Data

Once exposure and hazard data have been developed, the final key input to a seismic risk analysis is vulnerability relationships. Vulnerability curves relate ground motion at a site to damage. For building structures and contents, there are two primary methods for describing vulnerability relationships:

1. Fragility curves which estimate the percent of buildings in a range of damage states from None to Complete at a given ground motion intensity (see example in Chapter 2).
2. Damage ratio curves that directly relate ground motion intensity to a damage ratio (repair cost/replacement cost) as shown below

Note that fragility curves can be translated into



damage ratio curves by assigning a damage ratio to each damage state and taking the sum product of the probability of being in each damage state and the damage ratio for each damage state.

Building vulnerability is very region specific and a function of the materials used to build structures (e.g. wood, masonry, concrete, steel), local building construction practices and oversight, and the degree that earthquakes are or are not considered in the building design process. The most reliable way to quantify building vulnerability is to analyze damage and loss data for buildings similar to those in the study region. However, as was the case in specifying ground motion attenuation relationships, there often is

insufficient historical data for such an analysis. Given a lack of historical data, one option is to look at studies of past earthquakes in regions with similar construction. Numerous regional earthquake studies have been performed in different parts of the world, which have resulted in published vulnerability data, e.g. “Earthquake Protection” by Coburn and Spence. Additionally, some government sponsored earthquake risk tools have information related to vulnerability curves and how they can be derived. One example is the HAZUS software developed by FEMA in the United States. Although construction in the United States is much different than Bangladesh, the HAZUS documents provide a wealth of information on methodologies for developing vulnerability curves. In any case, the best starting point for the development of vulnerability curves is typically local structural engineers and/or engineers at local universities.

Another more detailed approach to developing vulnerability curves is to perform computer structural analyses of typical building structures in the region. These studies aim to quantify expected deformation of buildings at a range of ground motion intensities and then correlate those modeled deformations to building damage states and/or damage ratios. Studies such as these require well-qualified engineers who are familiar with local building design as well as vulnerability curve development. This approach has the benefit that it has the potential to produce vulnerability curves that best represent expected performance of buildings in the specific study region. However, there are many uncertainties in this process ranging from assumptions used in the structural analysis process to mapping building deformation to damage states and losses. Therefore, it is prudent to review vulnerability relationships developed in this manner to curves developed by other researchers.

In addition to modeling building and content damage due to ground shaking, potential damage from ground failure (liquefaction and

**Vulnerability Curve Development for Dhaka**

THE BUERP study utilized that work done by CDMP as part of their risk analysis. Fragility curves were developed for twelve predominant construction classes in the Dhaka region.

Designation	Description
C3L	Concrete Frame with Masonry Infill – Low Rise
C3M	Concrete Frame with Masonry Infill – Mid Rise
C3H	Concrete Frame with Masonry Infill – High Rise
C4L	Concrete Slab-Column Frame – Low Rise
C4M	Concrete Slab-Column Frame – Mid Rise
C4H	Concrete Slab-Column Frame – High Rise
LCL	Lightly Reinforced Concrete Frame – Low Rise
LCM	Lightly Reinforced Concrete Frame – Mid Rise
BCL	Masonry with Concrete Floor – Low Rise
BCM	Masonry with Concrete Floor – Mid Rise
BFL	Masonry with Flexible Floor/Roof – Low Rise
TSL+BAL	Tin and Bamboo

Fragility curve parameters are listed in the Appendix of the CDMP document titled “Earthquake Risk Assessment of Dhaka, Chittagong and Sylhet City Corporation Area”. In the analysis platform used in the BUERP study (CAPRA, described in a following section) vulnerability curves are represented by ground motion vs. damage ratio relationships. Therefore, the CDMP fragility curves were translated to damage ratio curves compatible with CAPRA by assigning a damage ratio to each building damage state.

The modeling of potential damage due to liquefaction was performed in accordance with methodologies described in the HAZUS technical manual. For each event modeled and each cluster, the probability of liquefaction was calculated based on the local ground motion and site liquefaction susceptibility. Estimated damage given that liquefaction occurred was based on the relationships provided by HAZUS. Analysis of lifeline distribution systems followed a similar approach, relying on the relationships in HAZUS. Landslide damage was not considered as landslide potential is small in the Dhaka study region.

landslide) should also be considered. This is typically handled by estimating the probability that ground failure occurs (given ground failure susceptibility and site ground motion) and multiplying that probability by the expected damage ratio given that ground failure does occur. The HAZUS technical manual provides a detailed methodology for assessing ground failure induced damage as well as methods for combining ground shaking and ground failure damage.

In addition to the development of vulnerability relationships for building structures, vulnerability curves also need to be developed for lifelines. For components of lifelines that are building structures (e.g. maintenance/control buildings) the methodologies described above can be utilized. For distribution systems such as water pipelines, specific vulnerability relationships need to be developed. Ground failure, as opposed to ground shaking, is often the primary cause of damage to distribution systems, in particular underground piping. Again, the HAZUS technical documentation provides detailed methodologies for the development of lifeline vulnerability functions.

### C. Analysis and Diagnosis

In addition to assembling the Exposure, Hazard, and Vulnerability input data for the risk analysis, it is necessary to have an analytic platform on which to perform the analyses and derive output. One option would be to develop computer code to read the input data, perform analyses, and write output data. However, given the complexities of the analysis process and the quantity of data being analyzed, developing even simple risk analysis software is a significant undertaking and would likely take more effort than setting up the input data.

As an alternative to writing new software code, existing risk analysis software can be utilized. It is recommended that users evaluate the capabilities of each system before deciding what software to use. Examples of currently available or in development risk analysis software tools are the

following:

HAZUS (<http://www.fema.gov/hazus>) – HAZUS is a nationally applicable standardized methodology that contains models for estimating potential losses from earthquakes, floods, and hurricanes. HAZUS uses Geographic Information Systems (GIS) technology to estimate physical, economic, and social impacts of disasters. It graphically illustrates the limits of identified high-risk locations due to earthquake, hurricane, and floods. Users can then visualize the spatial relationships between populations and other more permanently fixed geographic assets or resources for the specific hazard being modeled, a crucial function in the pre-disaster planning process.

OpenQuake (<http://www.globalquakemodel.org/openquake/about/>) – Earthquake risk analysis software being developed by GEM (Global Earthquake Model). At the end of 2014, the OpenQuake Platform will become available. This web-based risk assessment platform will offer an interactive environment for modeling, viewing, exploring, and managing earthquake risk by allowing users to access, manipulate, share and add data, models and tools for integrated assessment of earthquake risk. The source code behind the platform, engine and tools is openly available from a public repository [www.github.com/gem](http://www.github.com/gem).

CAPRA (<http://ecapra.org>) - CAPRA is a Disaster Risk Information Platform for use in decision-making that is based on a unified methodology and tools for evaluating and expressing disaster risk. Building on—and strengthening—existing initiatives, CAPRA was developed by experts to consolidate hazard and risk assessment methodologies and raise risk management awareness.

OASIS (<http://www.oasislmf.org>) - An open architecture loss modeling framework for the global community, aimed at creating an open marketplace for models and data leading to much wider access to understandable tools for

catastrophe risk management.

Some of the considerations that should be taken into account in choosing an analytical platform are the following:

- **Deterministic or Probabilistic Analysis** – if only a limited set of scenario deterministic events are to be analyzed then most risk analysis tools will be adequate. However, if probabilistic analyses are desired then required capabilities in the software are greater with accompanying more detailed and voluminous input and output. For example, CAPRA has extensive probabilistic analysis capabilities whereas HAZUS is more suited to scenario analyses.
- **Breadth of the risk study** – not all risk analysis software can accommodate all of exposure types and output that may be desired. HAZUS is capable of modeling multiple types of exposure ranging from buildings to lifelines to casualties and can consider ground shaking and ground failure sources of damage. On the other hand, while CAPRA input data can be formulated to correspond to varying hazards and exposures the process is not as straightforward.
- **Availability and format of input data** – software tools require that input data such as exposures, vulnerability, soil conditions, and source parameters be formatted in a specific manner. Typical input formats are GIS files, text files, and spreadsheets. Input format requirements should be reviewed in detail before starting an analysis to verify that data can be obtained or developed in the required format.

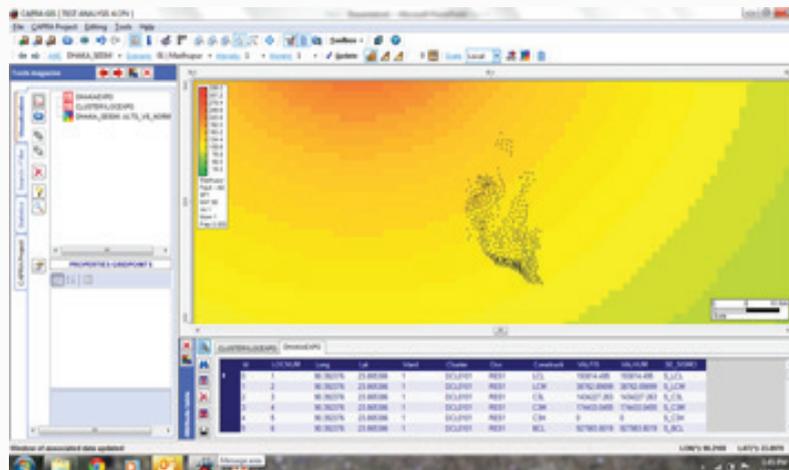
**BUERP Analysis Process**

For the BUERP study, the CAPRA suite of software was utilized for carrying out the core seismic hazard and building loss analyses. Additional calculations were performed outside of CAPRA as explained below. The following sections provide an overview of how Exposure, Hazard, and Vulnerability data are entered into the CAPRA software, results that are generated, and additional calculations performed outside of CAPRA.

**Exposure**

Exposure is input in the CAPRA-GIS software in the form of a GIS shape file. Each combination of location, occupancy, vulnerability and coverage (buildings and contents) was analyzed as a separate location resulting in 320,760 analysis locations (=540 clusters\*33 occupancies\*9 unique vulnerability curves\*2 coverages). The longitude and latitude values correspond to the centroid of the cluster. VALFIS represents the total value in the cluster for the given occupancy and construction class. SE\_SISMO indicates the building class (either S for structure or C for contents), these are user defined building class names.

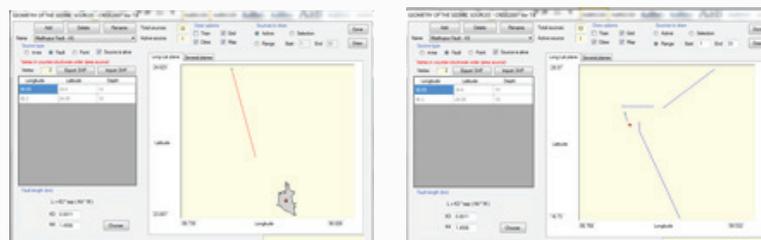
The CAPARA-GIS screenshot below shows the mapped cluster locations, the bottom pane shows a list of locations.



**Hazard**

**Seismic Sources**

Seismic source data was input and analyzed using the CAPRA CRISIS2007 seismic hazard analysis software. The CRISIS2007 software allows for input of seismic source locations, magnitudes, and seismicity parameters. The below figure shows screenshots from the CRISIS2007 source input screen.



### BUERP Analysis Process (con't)

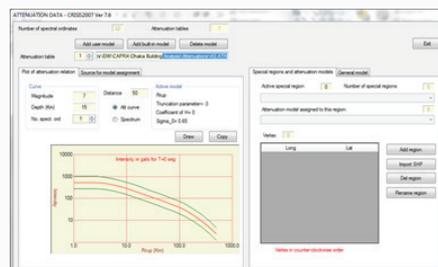
The information input for each source is as follows:

- Geometry:
  - o Longitude/Latitude of the fault endpoints
  - o Depth at each endpoint
- Seismicity:
  - o Median time between characteristic earthquakes
  - o Standard deviation of the characteristic earthquake
  - o Minimum possible magnitude of the characteristic earthquake
  - o Maximum magnitude of the characteristic earthquake
  - o Time since the last occurrence of the characteristic earthquake

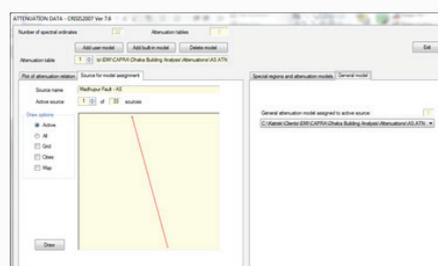
Note that the above seismicity input corresponds to a characteristic earthquake source; alternate information would be entered for a source modeled with a Gutenberg-Richter relationship. Additionally, the characteristic earthquake parameters allow for modeling of uncertainty in the characteristic earthquake magnitude. For the BUERP analysis input values were constrained to the expected magnitude (e.g. M7.5 for the Madhupur event) so that only one magnitude scenario was analyzed on each source.

#### Ground Motion Attenuation

CRISIS2007 allows for the input of user defined attenuations which were required for this project. A specific file format is needed, as specified in the CRISIS2007 user manual. Each attenuation equation has a separate file that lists ground motions for a set of magnitudes, distances, and periods. The magnitudes, distances, and periods are all user defined and are specified in header lines at the top of each attenuation file. Once the attenuation files are defined, they can be viewed within CRISIS2007 as shown in the below screen shot.



Each source is then assigned a specific attenuation as shown in the below screen shot. Because each source was modeled using three or four different attenuations, depending on whether the source is a surface or subduction source, individual sources were defined multiple times and assigned different attenuation equations. For example, the Madhupur fault was defined four times and assigned four different attenuation equations. If a probabilistic analysis was being undertaken, the recurrence rates for each of the sources would need to be divided by four.



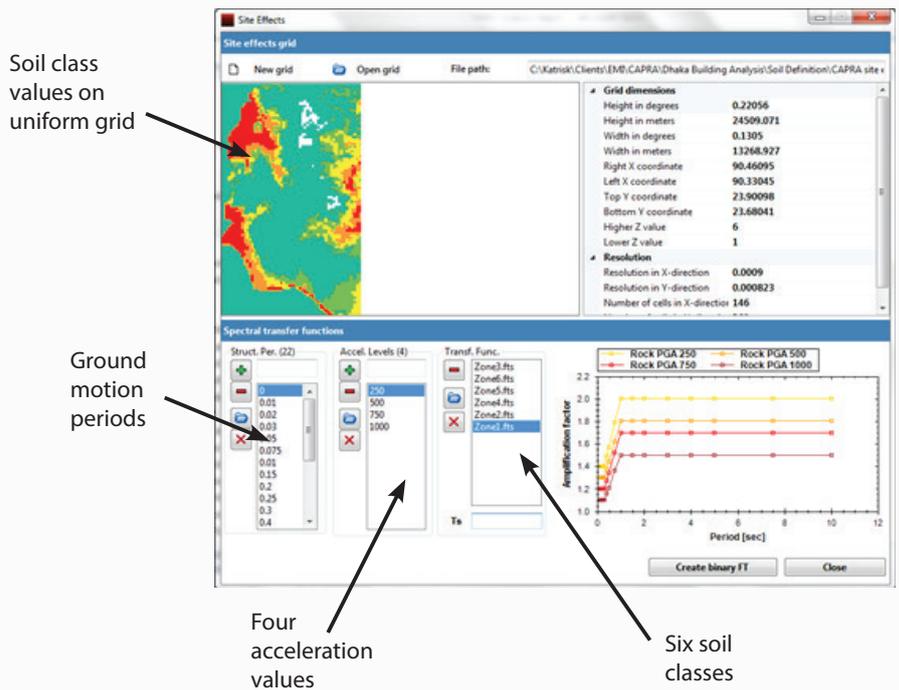
**BUERP Analysis Process (con't)**

**Soil Amplification**

Soil amplification in CAPRA-GIS is implemented through the use of soil amplification files. These files store ground motion amplification factors for varying levels of rock ground motion and period on a uniform grid.

The starting point in developing the site amplification files was the creation of a uniform grid of points across the study area. Each point was assigned a soil class by looking up the value from the soil classification map previously described for the respective grid point latitude and longitude. To create files usable in CAPRA-GIS, a program called "Site Effects" is utilized. The soil class grid file is input into Site Effects along with files that quantify amplification factors at four different acceleration values and for each period at which the ground motion is output, as described in the development of the attenuation files in the previous section.

A screenshot from the Site Effect software is shown below.



### Vulnerability

For implementation in CAPRA-GIS, separate files in a defined format are stored for each vulnerability curve. These curves contain a series of data points relating ground motion intensity to mean damage ratio and standard deviation around the mean damage ratio. Data within an example vulnerability curve file is shown below, in this case the structure curve for class LCM.

```
Amenaza Sismo
Física
25
0 0
17.79 0.00149 0.000746
35.59 0.00916 0.00454
53.39 0.0229 0.0112
71.18 0.0412 0.0197
88.98 0.0626 0.0293
106.78 0.086 0.0393
142.37 0.136 0.0586
177.96 0.186 0.0757
195.76 0.22 0.0857
213.55 0.264 0.0971
231.35 0.309 0.107
266.94 0.398 0.120
284.73 0.440 0.123
302.53 0.48 0.125
320.33 0.519 0.125
355.92 0.593 0.121
373.71 0.629 0.117
409.31 0.693 0.106
444.90 0.747 0.095
480.49 0.792 0.082
533.88 0.845 0.065
605.06 0.896 0.046
729.63 0.948 0.024
2509.22 0.999 0.0001
```

number of points in the vulnerability curve

ground motion – damage ratio % - standard deviation

A separate master file lists all of the vulnerability curve names and identifies what spectral ordinate to use from the ground motion file as shown below. In the exposure database, each location is assigned one vulnerability curve.

```
Amenaza Sismo
21
S_BCL,11,S_BCL(gal).fvu
S_BCM,13,S_BCM(gal).fvu
S_BFL,11,S_BFL(gal).fvu
S_C3H,15,S_C3H(gal).fvu
S_C3L,11,S_C3L(gal).fvu
S_C3M,13,S_C3M(gal).fvu
S_LCL,12,S_LCL(gal).fvu
S_LCM,14,S_LCM(gal).fvu
S_TSLBAL,11,S_TSLBAL(gal).fvu
.....
```

number of vulnerability curves

curve name, ground motion period, file name

### BUERP Analysis Process (con't)

#### Additional Calculations outside of CAPRA

As outlined above, the CAPRA software was used to model the core seismic hazard ground motions and building vulnerability, producing ground motion related building losses. Calculation of losses due to liquefaction as well as casualty and lifeline losses can be performed in CAPRA, however, the implementation is not straightforward. For that reason, ground motion output files were extracted from the CAPRA output and used as input into a separate analytical process coded in an open source computing platform called R. Losses generated in this fashion included:

- Liquefaction related building losses (and the combination of ground shaking and liquefaction losses)
- Losses to lifelines
- Casualty losses

These losses were calculated based on the methodologies outlined in the HAZUS software technical documentation.

### Areas of Potential Analysis Refinement

Knowledge of earthquake risk is imprecise and there are many opportunities to refine any risk study. The following are three aspects of the BUERP analysis where additional study could be of particular benefit.

Characterization of the Madhupur Fault – given the fact that the Madhupur fault is the closest known major fault to Dhaka, additional research into the location and potential size and frequency of events on the fault would significantly help characterize the risk in Dhaka.

Liquefaction potential – as discussed in this chapter, the land in many areas of Dhaka has been filled as the city has been expanded. Given that liquefaction can result in localized significant damage, additional study into the fill areas and potential for liquefaction to damage buildings and infrastructure would be beneficial.

Vulnerability of essential facilities – the performance of key facilities such as police and fire station, hospitals, and schools is critical to the response and recovery of a region. Gathering building specific vulnerability information would help in gaining an understanding of the degree to which those facilities will be operational following an event.

### D. Risk Output and Interpretations

Once output is generated from risk analyses it must be reviewed for accuracy and reasonableness. Basic quality assurance should be performed to make sure that input data was coded properly and that calculations were carried out correctly. Additionally, results should be reviewed against expectations and other similar studies when available to make sure they pass sanity checks. Given the results look reasonable, they then need to be assembled into a format that is usable and understandable for the intended audience.

#### BUERP Analysis Output and Review

##### Hazard Output From CRISIS2007

The hazard output from CRISIS2007 consists of ground motion footprints for each event analyzed. Ground motion maps can be visually reviewed within the CRISIS2007 software. Additionally, \*.AME output files can be created which are input to the CAPRA-GIS software where again the ground motion maps can be viewed.

As part of the BUERP quality assurance effort, an exposure file was set up in CAPRA-GIS that had one location at the centroid of each cluster. Special testing vulnerability curves were specified for these locations that assigned a damage ratio equal to the input ground motion (divided by a factor so the damage ratio is less than 100%) as shown below.

Amenaza Sismo
Física
31
0 0 0
100 0.01 .01
200 0.02 .01
300 0.03 .01
400 0.04 .01
500 0.05 .01
600 0.06 .01
700 0.07 .01
800 0.08 .01
900 0.09 .01
...

Portion of testing vulnerability curve where the damage ratio is set to the ground motion value divided by 10,000.

For one of the cluster locations, CAPRA-GIS was run and the damage ratios output. The distance from the location to the fault was calculated and that distance was entered into formula for the appropriate attenuation equation and compared to the output from CAPRA-GIS. This attenuation check was performed in a spreadsheet using the published attenuation equation, independent of the CARPA software. In this way, both the formulation of the attenuation within CRISIS2007 and the implementation within CARPA-GIS were verified.

### BUERP Analysis Output and Review (con't)

#### Building Loss Output From CARPA-GIS

Output from CAPRA-GIS scenario event analyses are stored in a GIS shapefile. The shapefile database file contains a list off all locations, the loss amount, and the damage ratio as shown below.

OID (Location ID)	PF_T1 (Loss)	PRF_T1 (Damage Ratio)
1	39456.2355	0.2036
2	17764.9202	0.4583
3	221067.2930	0.1541
4	41027.9076	0.2352
5	0.0000	0.0000
6	152644.7906	0.1645
7	26926.6784	0.3656
8	84806.8575	0.1799
9	3265.8646	0.0976
10	228054.1310	0.2036
11	236953.6820	0.4583
12	637548.0995	0.1541

The location ID can be mapped back to the exposure file that identifies the vulnerability curve for that location. Knowing the ground motion at the location (as described above), the vulnerability curve, and the damage ratio, implementation of the vulnerability curves can be verified.

In addition to checking implementation, overall loss results for each event should be sanity checked to the degree possible. For the BUERP study, the results could be compared to the CDMP loss analyses. The vulnerability curves as well as the ground motion attenuation curves used in the two studies are similar but not identical. Ground motion attenuations in the BUERP study were based on new NGA attenuations for surface faults and subduction attenuations for the subduction events. Additionally, the analysis platforms (HAZUS and CAPRA) are completely different. Nevertheless, results are relatively consistent as shown in the HVRA finding section of this report.

#### Casualty and Lifeline Losses

As described previously, casualty and lifeline losses were calculated outside of the CARPA software, as were building losses due to potential liquefaction. Quality assurance of the calculations performed in the statistical software called 'R' involved performing spreadsheet calculations for individual locations and comparing the results to the R program output.

Sanity checks of the lifeline damage consisted of comparison to the CDMP results, in the same manner as was done for buildings. In the case of casualty losses, the CDMP report estimated 88,000 fatalities for a Madhupur M7.5 event, about 1.2% of the population. This estimate is higher than the 0.5% calculated in this study. Two additional casualty models were also used to benchmark results.

### BUERP Analysis Output and Review (con't)

As part of the USGS PAGER initiative, Jaiswar et.al (2009) published a methodology relating fatality rates to building construction. A collapse rate is defined as follows, where S is intensity:

$$CR_i(S) = A_i \times 10^{\left(\frac{B_i}{S-C_i}\right)}$$

Given the Jaiswal parameters for A, B, and C for a non-ductile concrete frame, fatality rates would range from 0.5% to 1.65% for intensities 8-9, representative of a Madhupur M7.5 event. This range is consistent with the CDMP results.

Additionally, the methodology outlined by Coburn and Spence (1992) was applied to the Dhaka scenario and resulted in casualty estimate of 83,000, also similar to the CDMP results.

Given uncertainties in model parameters and benchmarking against other casualty methodologies, a reasonable range of estimated fatalities for a Madhupur M7.5 event is 40,000 to 150,000 for the Dhaka study region (population 7,279,644), or an overall casualty rate of 0.5% to 2.1%.

## E. Stakeholders' Validation

As a project progresses, and particularly near the end of the project, it is important to get feedback from the stakeholders who will be using the information provided by the study. At a minimum, feedback on the following items should be obtained:

- Are the results of the study understandable and actionable?
- Do the results make intuitive sense and if not what additional information could be provided to aid in the understanding and interpretation of results?
- Are there areas/topics where additional analyses are needed or requested?
- Are the technical aspects of the work understandable to the degree that others could extend and enhance the analyses at a later date?

### Example of Stakeholders' Validation Activity in Dhaka

As described in the HVRA Methodology section of this guidebook, a Focus Group, Advisory Committee, and Scientific Committee were set up to provide input and guidance during the entire course of the project. In December 2013, a final project field investigation was performed in Dhaka with the goal of presenting results and getting feedback prior to the completion of the Risk Atlas and Guidebook. Those meetings resulted in feedback that mostly centered around a desire to provide more detail related to the HVRA analysis tools including data input, data output, and modeling choices. Following the meeting, additional detail was added to this Guidebook in an attempt to address that feedback to the degree that the project scope and timeline allowed.

## 4 Urban Disaster Risk Index

Risk indicators and “hotspot” analysis identify concentrations of the highest impact areas in order to focus respective disaster planning and decision making. The hotspots are based on wards, which are the smallest administrative unit relevant in emergency planning, preparedness and policy making. These are the smallest units in the study in which population census data is available.

Hotspots are defined by a combination of a number of critical indicators. These indicators are categorized into two: the expected direct physical damage and losses, and the potential for aggravating impact of the direct damages by the social fragility and coping capacity of the different Wards in Dhaka. These two categories form, respectively, Physical Risk Index (PRI) and the Impact Factor Index (IFI). The theoretical and analytical methodological framework for the Urban Disaster Risk Index (UDRI) is based on the work of Cardona et al. (2005). According to this procedure, the Urban Disaster Risk Index is obtained by multiplying the Physical Risk Index (PRI) (from existing loss scenarios) by an Impact Factor Index (IFI), based on variables associated with the socio-economic conditions of each Ward, according to the following relationship:

$$\text{UDRI} = \text{PRI} (1 + \text{IFI})$$

The selection of impact factors is based on the well accepted definition of social vulnerability as “the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard” (At Risk, 2004). At the same time, the Impact Factor will increase if the capacity to overcome vulnerability in face of hazards is not present. Thus, the impact factor also includes Coping capacity Indicators, such as available means of disaster preparedness

and risk mitigation, emergency response capacities, and other buffers and resources for reconstruction and recovery. The Physical Risk Index is a function of the following indicators: Building Damage, Fatalities, and Economic Loss. The Impact Factor Index is a function of the following indicators: Population Density, Vulnerable Population (Elderly, Very Young, Disabled, Illiterate, Gender Ratio, Dilapidated Housing), Lack of Access to Services (Electricity, Water, and Sanitation) and Lack of Coping Capacities (Hospitals, Schools and Police Stations). The Urban Disaster Risk Index is simply a combination of the PRI and the IFI. The complete methodology is discussed in the section below

### 4.1 Definition of Earthquake Scenarios

Chapter 2 of this Guidebook described the Magnitude 7.5 event on the Madhupur fault as one of two scenario events that have the greatest impact on the city of Dhaka. Accordingly, this scenario provides the crucial indicators for assessing impact on Dhaka and is used for the hotspot analysis.

### 4.2 Earthquake Risk Indicators

The earthquake risk indicators shown in Table XX are modelled based on the Magnitude 7.5 event on the Madhupur fault described in Chapter 3 and include: Building Damage, Fatalities, and Economic Loss. Importance weights for each of these indicators were derived through an expert survey according to the Analytical Hierarchy Process (AHP) methodology, and a weighted sum of these indicators was obtained to derive the Physical Risk Index score in each ward.

Table 4. Earthquake Physical Risk Indicators (PRI) and weights

Physical Risk Index	Indicators	Weight
Building Damage	<b>RE1: Building Damage Ratio</b> ; given as ratio of collapsed and severely damaged buildings to the total building stock in the Ward	0.26
Fatalities	<b>RE2: Fatality Ratio</b> ; given as number of fatalities per 1000 population in a Ward	0.46
Economic Losses	<b>RE3: Economic Loss Ratio</b> ; given as the ratio of the lost building value to the total building value in a Ward	0.28

### 4.3 Drivers of Social Vulnerability in Dhaka

Social vulnerability is most apparent after a hazard event has occurred, when different patterns of suffering and recovery are observed among certain groups in the population. While all people living in hazard areas are vulnerable, the social impacts of hazard exposure often fall disproportionately on the most socially vulnerable people in society – the poor, minorities, children, the elderly and disabled for instance. These groups are often the least prepared for an emergency, have the fewest resources with which to prepare for a hazard event, tend to live in the highest-risk locations in substandard housing, and lack knowledge or social and political connections necessary to take advantage of resources that would speed their recovery. With increased exposure of people, livelihoods, and property to earthquake risk in Dhaka, the potential for social and economic impacts of disasters cannot be ignored. Indicators of social vulnerability and coping capacities have been used here to accomplish these tasks.

As the indicators should be reproducible and used for benchmarking over time, an important criterion was to use only indicators which are readily available and can be collected over time without the need of special surveys. Accordingly, the starting point for the selection of socio-economic impact factors is the demographic data available within the publically available Census data at the Ward level. Selection of the

key indicators was identified using concepts used by various researchers and published in academic literature against the real conditions and the local context of Dhaka. The selected indicators were ranked according to the Analytical Hierarchy Process (AHP) by experts in Dhaka.

This section shows three maps: the PRI, IFI, and UDRI. It shows the ranking of each ward according to each index.

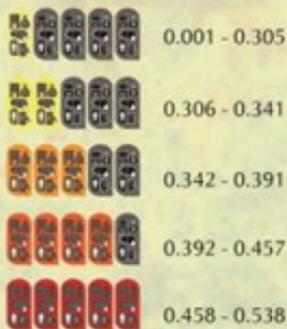
Social Vulnerability (Weight = 0.77)	Indicator	Weight	
Population Density	<b>S<sub>v1</sub>: Population Density</b> given as the population in a Ward divided by the land area (km <sup>2</sup> )	0.23	
Children	<b>S<sub>v2</sub>: Children</b> given as the ratio of Children (Age group 0-9) per 1000 population	0.13	
Elderly	<b>S<sub>v3</sub>: Elderly</b> given as the ratio of Elderly (Age group 65 and over) per 1000 population	0.08	
Disabled	<b>S<sub>v4</sub>: Disabilities</b> given as the ratio of persons with disabilities (all types) in a Ward per 1000 population	0.26	
Illiterate	<b>S<sub>v5</sub>: Illiteracy</b> given as the ratio of illiterate population in a Ward per 1000 population	0.03	
Gender	<b>S<sub>v6</sub>: Gender</b> given as the ratio of females to males (aged 3 to 29) <u>not</u> attending school	0.04	
Dilapidated Housing	<b>S<sub>v7</sub>: Dilapidated Housing</b> given as the ratio of Jhupri structures to total buildings in a Ward	0.16	
Lack of Access to services	<b>S<sub>v8</sub>: Electricity</b> given as the ratio of population with no electric connection per 1000 in a Ward	0.08	0.23
	<b>S<sub>v9</sub>: Water</b> given as the ratio of population with no access to tap water per 1000 in a Ward	0.68	
	<b>S<sub>v10</sub>: Sanitation</b> given as the ratio of population with no improved sanitation facilities (non water sealed toilet facilities) per 1000 in a Ward	0.24	

Coping Capacities (Weight = 0.23)	Indicator	Weight
Hospital	<b>C<sub>c1</sub>: Hospitals</b> given as the number of hospitals in a Ward (ranked by hospital type)	0.56
School	<b>C<sub>c2</sub>: Schools</b> given as the number of schools in a Ward (ranked by school type and capacity)	0.28
Police	<b>C<sub>c3</sub>: Police Stations</b> given as the number of police stations in a Ward	0.16

# Physical Risk Index

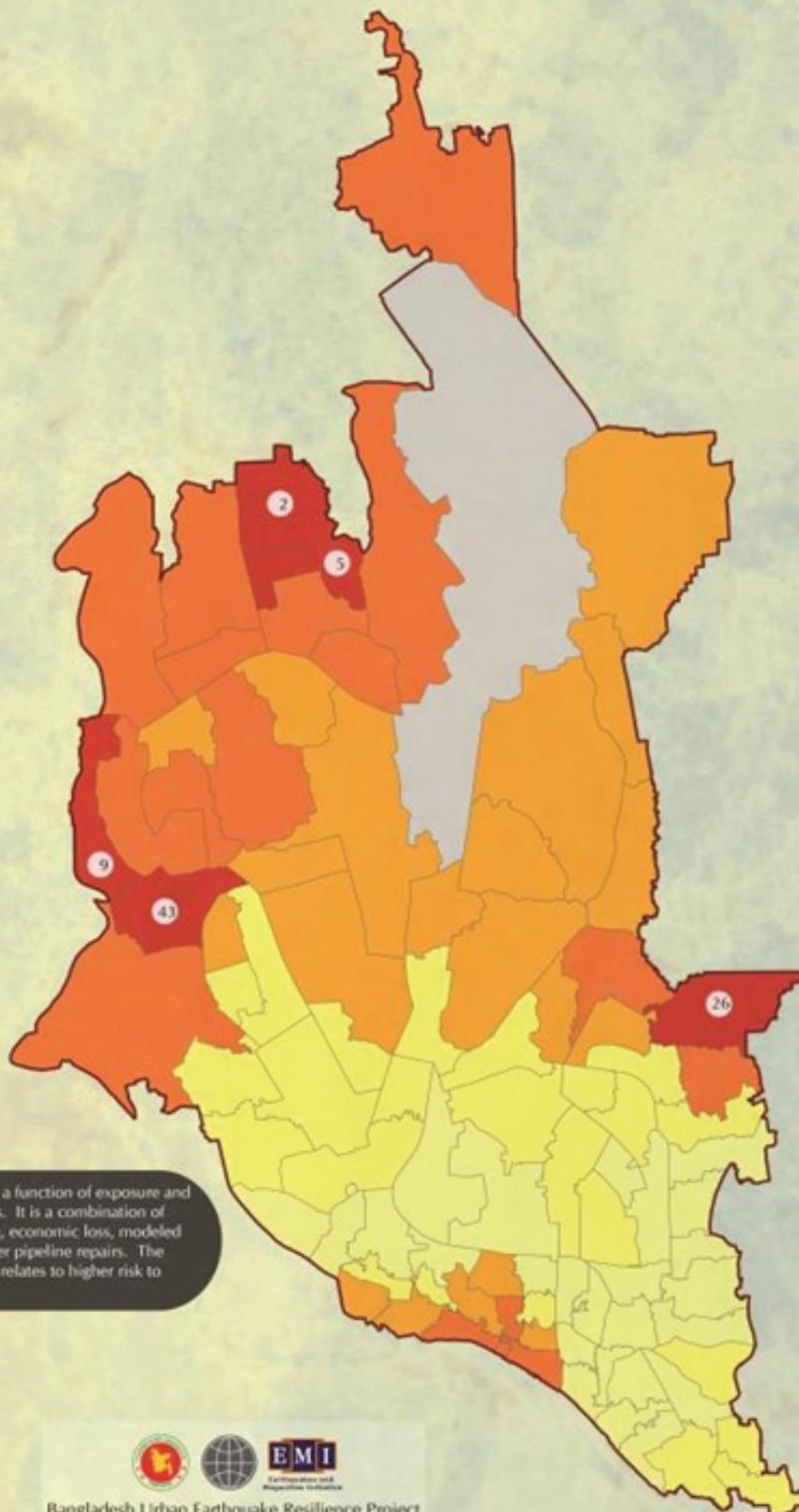
## M7.5 Madhupur Fault Event

### Physical Risk Index



### 5 wards with highest PRI

Ward	PRI
5	0.538
2	0.535
26	0.499
9	0.488
43	0.475



The Physical Risk Index is a function of exposure and modeled loss and fatalities. It is a combination of potential building damage, economic loss, modeled fatalities, and potable water pipeline repairs. The index values closer to 1.0 relates to higher risk to earthquakes.

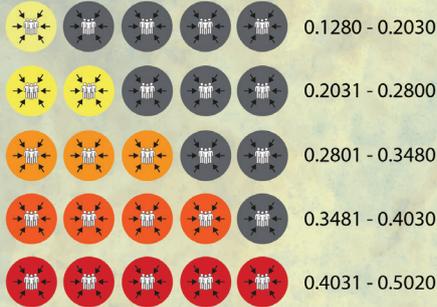
Source: Bangladesh Urban Earthquake Resilience Project Hazards, Vulnerability, and Risk Assessment



# Impact Factor Index

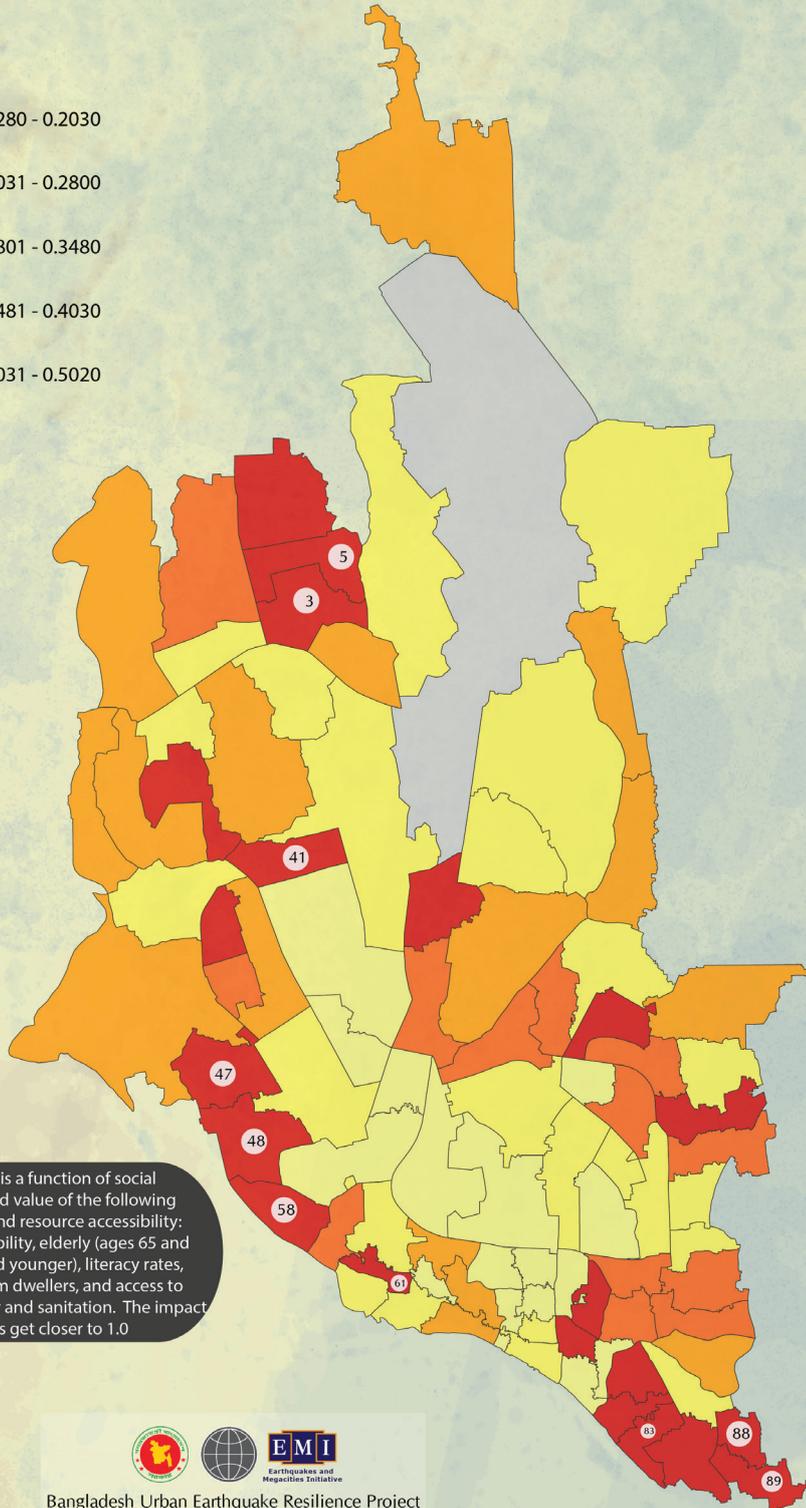
## M7.5 Madhupur Fault Earthquake Event

### Impact Factor Index (IFI)



### 10 wards with highest IFI

Ward	IFI
5	0.502
48	0.499
3	0.496
41	0.480
47	0.472
88	0.459
83	0.457
58	0.444
89	0.441
61	0.438



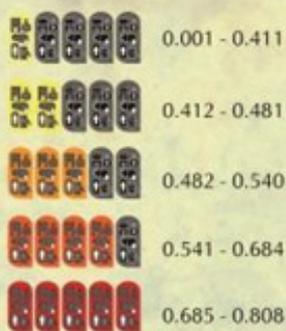
The Impact Factor Index is a function of social indices. It is the weighted value of the following demographic datasets and resource accessibility: population density, disability, elderly (ages 65 and older), young (ages 9 and younger), literacy rates, female to male ratio, slum dwellers, and access to electricity, potable water and sanitation. The impact increases as the IFI values get closer to 1.0

Source: Bangladesh Urban Earthquake Resilience Project Hazards, Vulnerability, and Risk Assessment

# Urban Disaster Risk Index

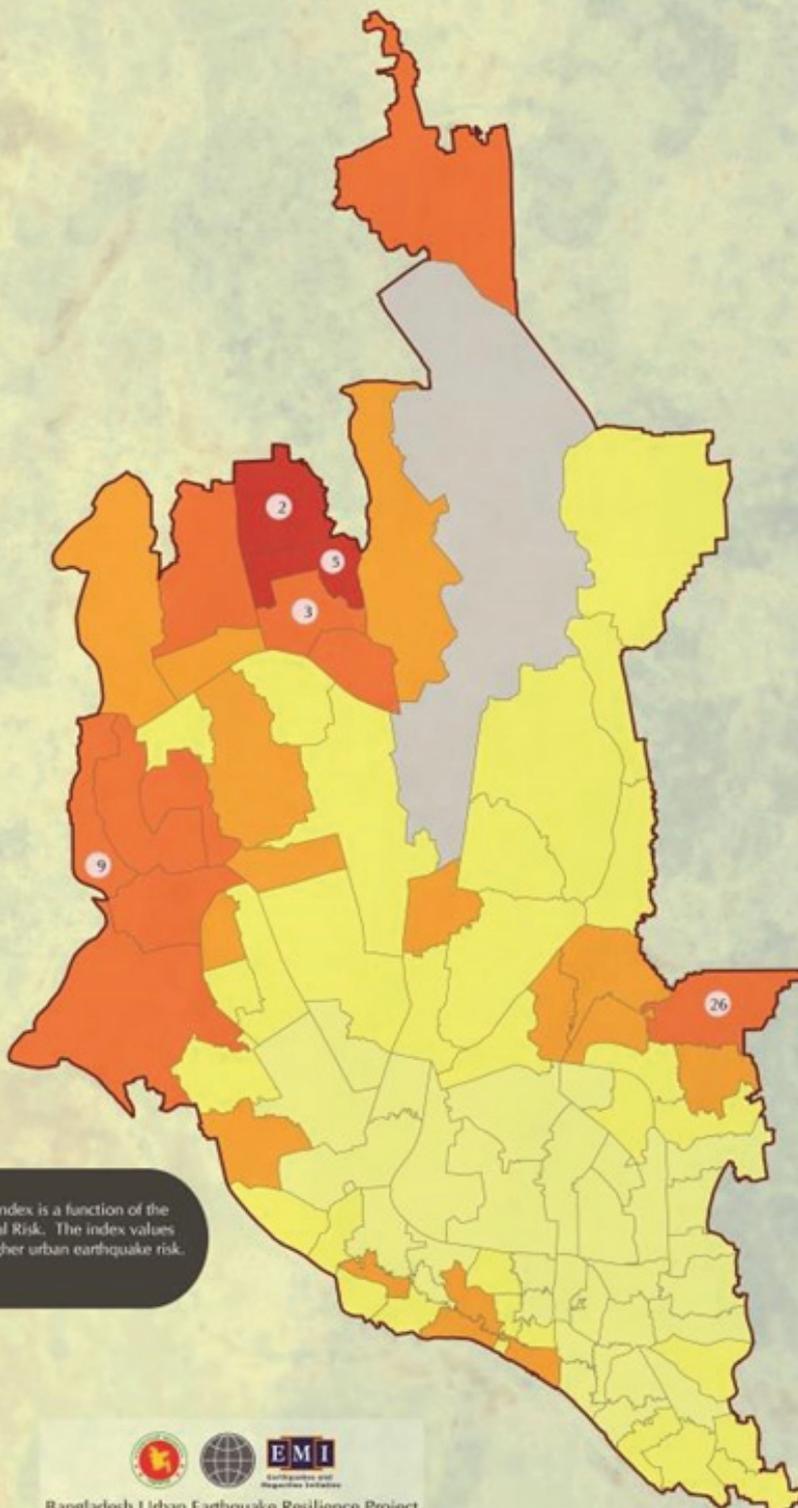
## M7.5 Madhupur Fault Event

### Urban Disaster Risk Index



### 5 wards with highest UDRI values

Ward	UDRI
5	0.808
2	0.758
3	0.684
26	0.659
9	0.651



The Urban Disaster Risk Index is a function of the Impact Factor and Physical Risk. The index values closer to 1.0 relates to higher urban earthquake risk.

Source: Bangladesh Urban Earthquake Resilience Project Hazards, Vulnerability, and Risk Assessment

# 5 HVRA Findings

## 5.1 How are the findings of the HVRA investigation presented?

This chapter highlights some of the key results of the HVRA (Hazard, Vulnerability, Risk Assessment) component of the Bangladesh Urban Earthquake Resilience Project.

The HVRA findings are presented in five categories, namely: (1) Scenario Ground Motions, (2) Scenario Building and Content Losses, (3) Building Damage State Distributions, (4) Model Uncertainty and Stress Tests, (5) Lifelines.

Chapter 3 of this Guidebook described the various input data required for the Dhaka earthquake risk analysis as well as the CAPRA analysis tools. The remainder of this chapter provides a summary of analysis results. Results are presented for two of the five event scenarios shown in Chapter 3, namely:

- A Magnitude 7.5 event on the Madhupur fault;
- A Magnitude 8 event on the Plate Boundary 2 fault.

These two events have the greatest impact on the city of Dhaka. In addition, results are shown for a magnitude 6 event at an arbitrary location under Dhaka representing the possibility for a more moderate event in closer proximity to the city. This is consistent with the scenarios used in the CDMP report.

### A. Scenario Ground Motions

These maps show ground motion distributions (peak ground acceleration) for the three scenarios presented in this chapter. The Madhupur fault event is to the north of the city. Ground motions generally decrease from north to south and are amplified in areas of soft soil. The Plate Boundary 2 fault is to the east of the city and ground motions decrease going east to west. The Magnitude 6 event under Dhaka has the highest ground motions near the arbitrary location of the fault. Note, an event of this nature could occur anywhere but the likelihood of such an event is less than the Madhupur or Plate Boundary 2 events. These maps show that all areas of Dhaka are subject to potentially strong ground motions.

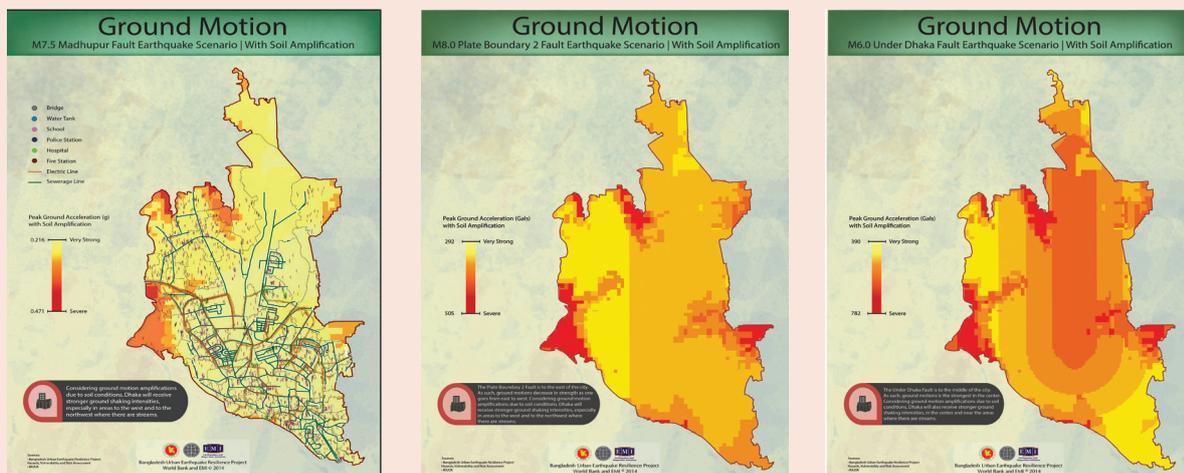


Figure 6. Ground Motion Distributions for Dhaka Earthquake Scenarios

**B. Scenario Building and Content Losses**

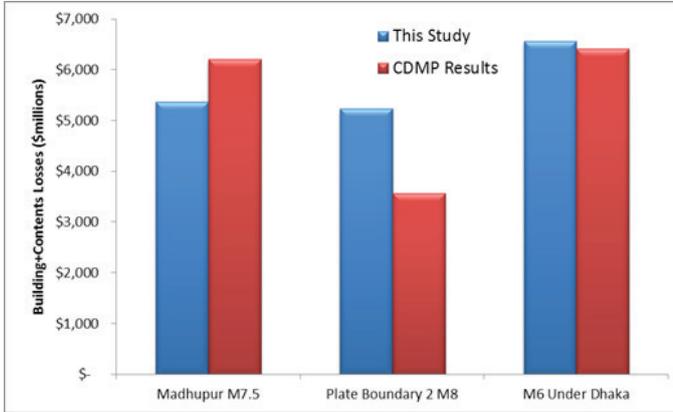


Figure 7. Building and Content Losses

This chart shows building and contents losses for the three scenarios. Total losses are in the range of \$5 to \$7 billion. Total estimated exposure values are approximately \$17 billion buildings and \$11 billion contents. Therefore, losses represent approximately 25% of total exposed values. As indicated in the chart, there are multiple scenarios that all result in comparable and extensive losses to Dhaka.

Also shown in the chart are estimated losses from the CDMP report. Overall, those losses are quite consistent. The major differences are likely due to differences in ground motion attenuations utilized in the two studies, in particular for the Plate Boundary 2 source where this study utilized attenuation equations specific to subduction type events.

The map shows the building damage ratio distribution for the Madhupur event. This is one illustrative example as it is possibly the most likely event of the three scenarios. It should be kept in mind that other scenarios would cause different geographic distributions of losses as indicated in the previous ground motion maps.

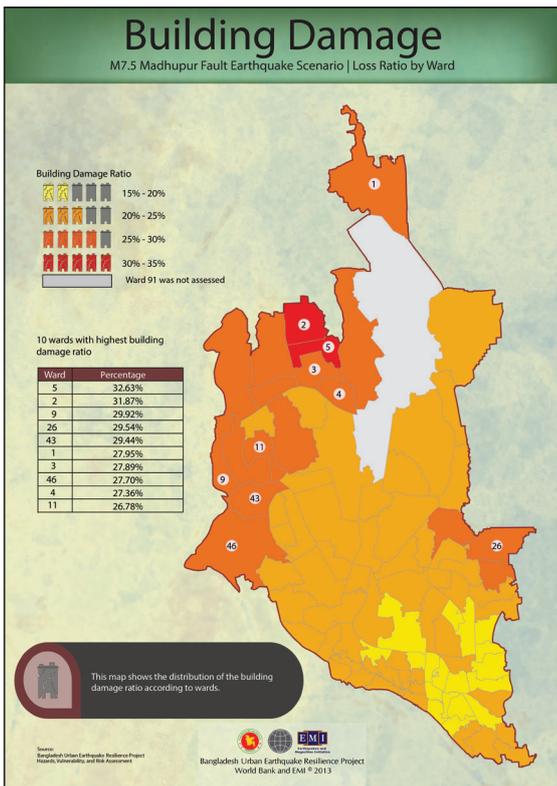


Figure 8. Madhupur M7.5 - Building Damage Ratio by Cluster

### C. Building Damage State Distributions

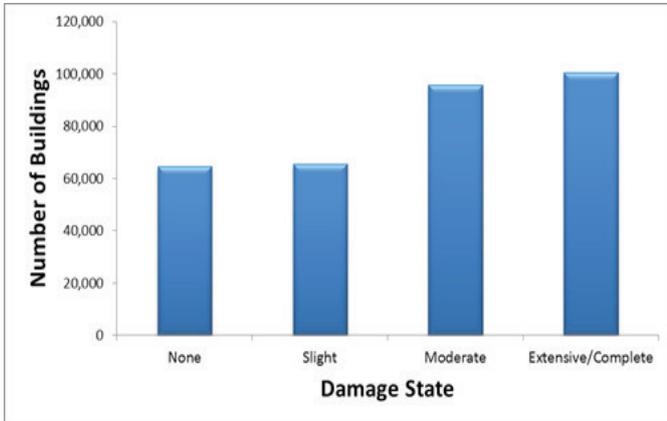


Figure 9. Madhupur Event Building Damage State Distributions

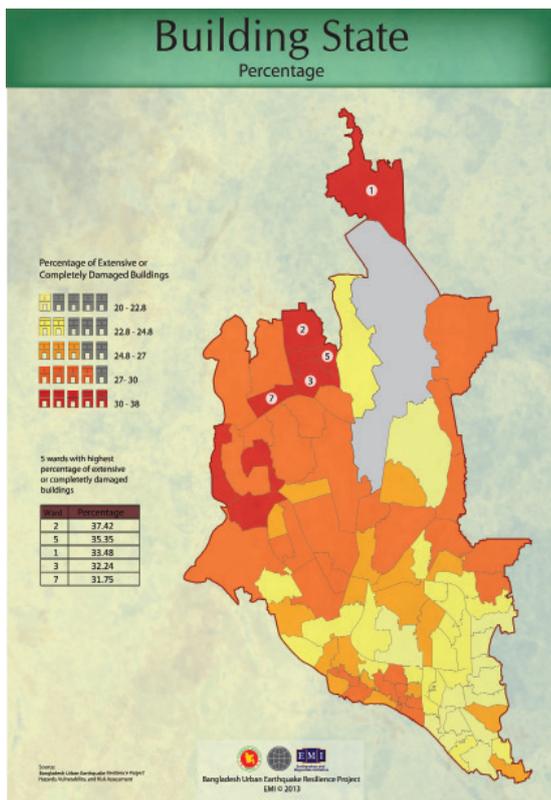


Figure 10. Madhupur Event - Percentage of Buildings in Extensive/Complete Damage States

In addition to looking at financial losses, damage state distributions are useful in understanding the overall physical damage to the building stock in an event. Out of the estimated 327,000 buildings in Dhaka, this chart shows how many are in each of four damage states. For concrete buildings with masonry infill walls, a common building type in Dhaka, the damage states are defined as follows:

- Slight - Diagonal (sometimes horizontal) hairline cracks on most infill walls; cracks at frame-infill interfaces.
- Moderate - Most infill wall surfaces exhibit larger diagonal or horizontal cracks; some walls exhibit crushing of brick around beam-column connections. Diagonal shear cracks may be observed in concrete beams or columns.
- Extensive - Most infill walls exhibit large cracks; some bricks may dislodge and fall; some infill walls may bulge out-of-plane; few walls may fall partially or fully; few concrete columns or beams may fail in shear resulting in partial collapse. Structure may exhibit permanent lateral deformation.
- Complete - Structure has collapsed or is in imminent danger of collapse due to a combination of total failure of the infill walls and non-ductile failure of the concrete beams and columns.

In the Madhupur scenario, 30% of the buildings are modelled to be in extensive or complete damage states.

The map shows the geographic distribution of buildings in extensive or complete damage states.

### D. Model Uncertainty and Stress Tests

As discussed previously, there are numerous uncertainties associated with the parameters that make up an earthquake risk analysis. When performing a risk analysis, as a means to understanding these uncertainties, it is helpful to test the sensitivity of results to alternate modelling assumptions. These charts show three examples of alternate modelling assumptions for the Madhupur event and illustrate that with reasonable alternate assumptions loss estimates can vary by 50% or more from the mean expected loss.

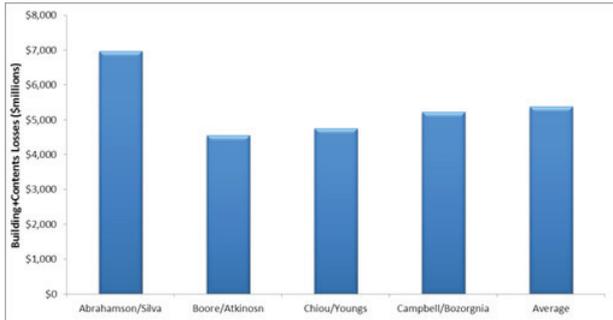


Figure 11. Alternate Attenuation Equations

Previous results in this chapter showed losses for the Madhupur event which are the average of the losses calculated using four individual ground motion attenuation equations. This chart shows losses for each individual attenuation equation. There is approximately a 50% increase in losses in going from the lowest to highest outcome.

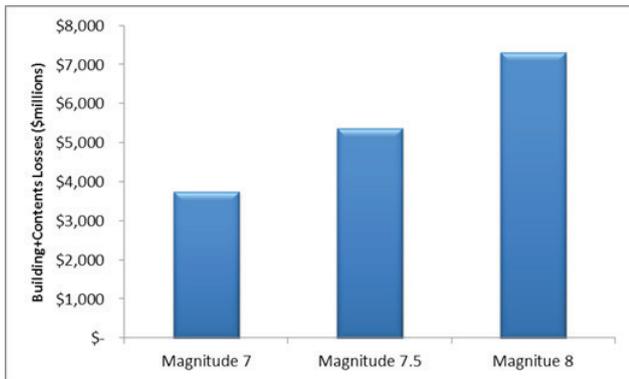


Figure 12. Alternate Magnitude

The maximum magnitude of the Madhupur event is estimated to be 7.5. However, there is uncertainty in the estimate given lack of data regarding its potential length and area of rupture. This chart shows loss results for magnitude 7, 7.5 and 8 events. A magnitude 8 event produces losses approximately twice a magnitude 7 event.

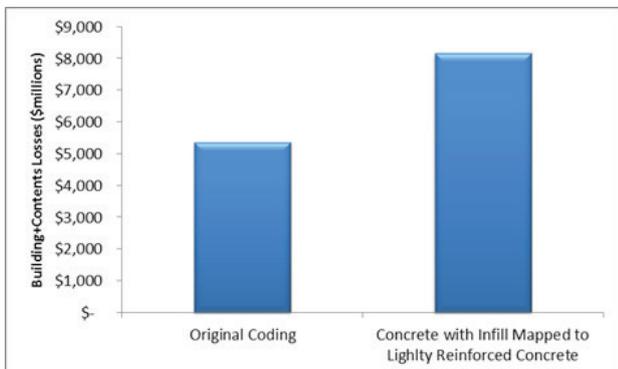


Figure 13. Alternate Vulnerability

In the risk analysis, a majority of exposure in Dhaka is coded as reinforced concrete with masonry infill with a lesser amount coded as a more vulnerable lightly reinforced concrete class. Given the lack of past damage experience in Bangladesh there is uncertainty in the derivation of vulnerability curves. In this sensitivity test, all concrete was coded as the more vulnerable lightly reinforced concrete class which results in a 50% increase in losses.

### E. Lifelines

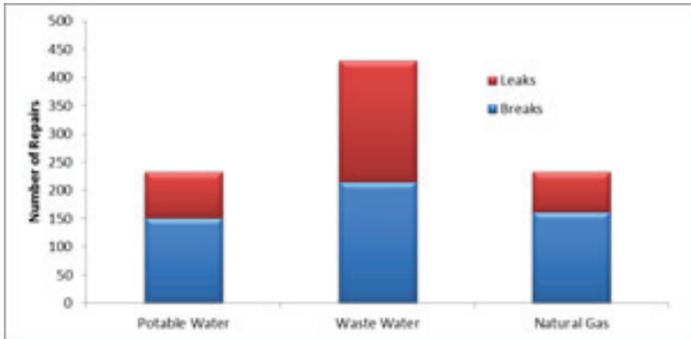


Figure 14. Madhupur Event Lifeline Repairs

Functioning of lifelines such as water and power systems and transportation are critical for post-earthquake recovery. Therefore, it is important to assess the degree of damage expected to lifelines and the time it will take to restore them to functionality.

As an example, the chart shows the expected number of repairs for Potable Water, Waste Water, and Natural Gas pipelines for the Madhupur event scenario. The map shows the geographic distribution of water pipeline repairs.

A detailed inventory of key lifeline components as well as estimated repair times based on damage state can help prepare for post-earthquake impacts and response.

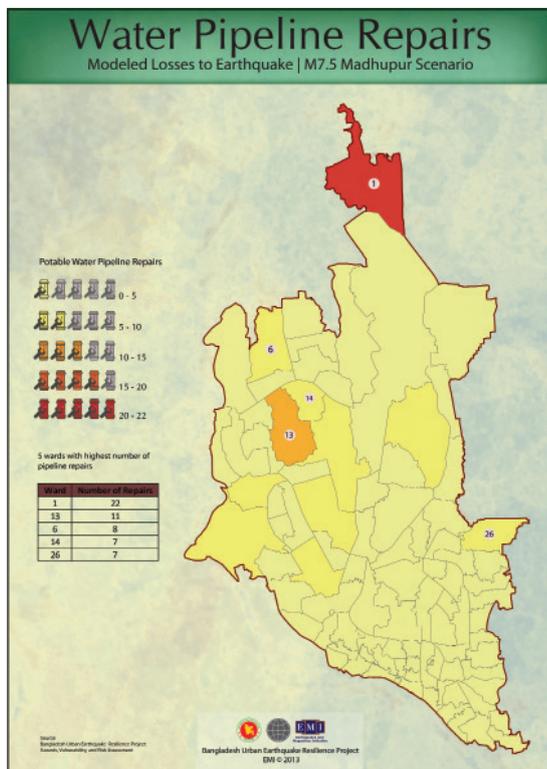


Figure 15. Madhupur Event Water Line Repairs

## 6 Annexes

### *Annex 1. List of HVRA Focus Group members*

Sl. No.	Organization and address
1.	Dept. of CE, BUET
2.	Dept. of CE, BUET
3.	Dept. of URP, BUET
4.	CEGIS
5.	Prime Minister's office, AFD, Operation and Plan Directorate
6.	EED, Ministry of Education
7.	Health Eng. Dept. (HED)
8.	ADPC
9.	Director, Planning-1 BWDB
10.	DPDC
11.	Public Works Dept. (PWD), Purta Bhaban, Segunbagicha
12.	DDM
13.	Geological Survey of Bd. (GSB)
14.	Titas Gas, Dhaka
15.	BMD
16.	Fire Service and Civil Defence
17.	Dhaka Electric Supply Co. (DESCO)
18.	Dhaka WASA
19.	RAJUK
20.	HBRI
21.	Dhaka North City Corporation
22.	Dhaka South City Corporation
23.	BTRC, IEB building, Ramna, Dhaka-1000
24.	Capital Law Chamber

Sl. No.	Organization and address
25.	Institute of Disaster Management and Vulnerability, DU
26.	Pioneer Insurance Co. Ltd.

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