Review of disaster risks and structural vulnerability assessments in Myanmar

VOLUME 1 – Overview of Yangon's disaster risk profile

INTRODUCTION

Myanmar is the largest country in Southeast Asia by area with a population of over 50 million and is highly exposed to natural disasters. Myanmar ranks 2nd out of 187 countries in the 2016 Global Climate Risk Index[1] and 9th out of 191 countries in the Index for Risk Management (INFORM)[2]. Over the past 25 years, Myanmar has suffered 24 disaster events, affecting more than 4 million people and causing US$4.7 billion in damages[3]. A preliminary financial risk assessment estimated expected annual economic losses of over US$184 million due to natural disasters, equivalent to 0.9 percent of GDP[4]. Given the importance of the city of Yangon, many studies that look at natural disasters conducted in Myanmar have focused on the city. In particular, there is a rich body of reports that analyze various aspects of natural hazards and the associated vulnerabilities related to Yangon. At the same time, the country is considering major revisions to its regulatory structure. As a prelude to undertaking this reform, it is crucial to have a complete picture of existing and ongoing natural hazard studies and vulnerability reports that will underpin the subsequent regulatory structure. Accordingly, this study was initiated to compile, review, and assess the available studies related to natural hazards in Yangon.

Myanmar Southeast Asia Disaster Risk Management (SEA DRM) Project[5] aims to improve the drainage system and structural performance of selected public facilities in Yangon, as well as to enhance disaster response. A component of this project 'Safer Public Facilities and Critical Infrastructure' includes technical assistance activities for a Building Regulatory Capacity Assessment (BRCA), which involves a risk assessment of critical infrastructure in Yangon and a review of the city's institutional capacity.

This document, ***Review of Disaster Risks and Structural Vulnerability Assessments in Myanmar*** is a two-volume report providing the analytical baseline for the BRCA. Findings and recommendations from this review will be used to further refine the objectives and scope of the planned BRCA technical assistance.

Volume 1 - Overview of Yangon's disaster risk profile is a literature review of existing hazard, exposure, vulnerability and damage assessments in Yangon, and a synopsis of relevant laws and regulations. This volume serves as a detailed account of the large number of DRM-related resources that have been developed to date. No independent vulnerability assessments were conducted as part of this activity.

Volume 2 - Analysis of research findings and implications on disaster resilience of Yangon's built environment is an analysis of select reports from Volume 1 that have implications for DRM planning, policies, and institutions in Yangon. This volume, which is organized topically as with Volume 1, serves as a high-level synthesis of the reference documents and highlights their key messages for decision-makers.

The background research, interviews, and analysis for this review were carried out with financial support from the Global Facility for Disaster Reduction and Recovery (GFDRR) through the Japan - World Bank Program for Mainstreaming Disaster Risk Management in Developing Countries Trust Fund.

1. GermanWatch. 2016. Global Climate Risk Index 2016. https://germanwatch.org/fr/download/13503.pdf
2. INFORM (Index for Risk Management). 2016. Results Report 2016 (http://www.informindex.org/Portals/0/InfoRM/2016/INFORM%20Results%20Report%202016%20WEB.pdf); Myanmar Country Profile (http://www.inform-index.org/Portals/0/Inform/2016/country_profiles/MMR.pdf).
3. Preliminary World Bank analysis based on data from EM-DAT database (http://www.emdat.be/).
4. World Bank and Global Facility for Disaster Reduction and Recovery. 2012. ASEAN. Advancing Disaster Risk Financing and Insurance in ASEAN Member States: Framework and Options for Implementation
5. Financed by the World bank

ACKNOWLEDGMENTS

This two-volume report was prepared by consultants (Miyamoto International) under the supervision of World Bank staff as input for the Myanmar Southeast Asia Disaster Risk Management (SEA DRM) Project (P160931). The report was prepared through financial support from the Global Facility for Disaster Reduction and Recovery (GFDRR) through the Japan - World Bank Program for Mainstreaming Disaster Risk Management in Developing Countries Trust Fund.

The significant contributions of Daw Hlaing Maw Oo (Secretary) and Daw Hnin Ei Win (Section Head – Engineering Department of Buildings) from the Yangon City Development Committee (YCDC), U Saw Htwe Zaw (Vice Chairman) of the Myanmar Earthquake Committee (MEC), and organizations interviewed during the February 2019 mission are acknowledged.

The World Bank team consisted of Mr. Michael Bonte-Grapentin (Senior Disaster Risk Management Specialist), Mr. Thomas Moullier (Senior Urban Specialist), Mr. Frederick Krimgold (Senior Consultant), Ms. Theresa Abrassart (Urban Development Consultant), Mr. Andrew Hurley (Engineering Consultant), Ms Khin Aye Yee (Operations Officer), Ms Thida Aung (Program Assistant), and Mr Aung Naing Oo (Consultant). The guidance of the task team throughout the project and their thoughtful review of this report is appreciated. The report was reviewed and finalized by Keiko Saito (Senior Disaster Risk Management Specialist), Dixi Mengote-Quah (Infrastructure Specialist), and Nick John Paul (Editor), and guided by Jolanta Kryspin-Watson (Lead Disaster Risk Management Specialist).

EXECUTIVE SUMMARY

The World Bank's (WB) Southeast Asia Disaster Risk Management Project for Myanmar has the overall goal of improving the drainage system and structural performance of selected public facilities in Yangon, as well as enhancing disaster response.

The project comprises the following five components:

- Component C1: Strengthening Financial Planning for Disaster Resilience
- Component C2: Urban Flood Risk Management
- Component C3: Safer Public Facilities and Critical Infrastructure
- Component C4: Project Management
- Component C5: Contingent Emergency Response

One of the subcomponents under Component C3 is dedicated to the building regulatory and vulnerability assessment (VA) with the goal of strengthening the institutional capacity of the Yangon City Development Committee (YCDC).

The objective of this two-volume report is to present a comprehensive analysis of the risk environment based on the available literature.

This document **(Volume 1)** consolidates and presents the known risks to Yangon from natural and secondary hazards based on the available literature. It then proceeds to identify gaps in terms of risk information. The review shows that various government agencies, international organizations, and participating individuals have made significant contributions to the study of the risk environment in the city, and a number of high-quality technical reports have been prepared. Volume 2 of the report is an analysis of select reports from Volume 1 that have particular implications for DRM planning, policies, and institutions in Yangon.

The hazard environment impacting a city can be classified according to two types of hazards: acute or chronic. Acute natural hazards (earthquake, cyclone, flood, landslide, tsunami, and volcano eruption) have a low probability of occurrence but a large impact. Chronic hazards (urban fire, epidemic disease, public health, and building collapse not related to acute hazard) have a higher likelihood of occurrence but usually impact a smaller segment of the population. To develop a resilient city and community, both classes of hazard need to be addressed. This report focuses specifically on earthquakes, cyclones, floods, and urban fires. There is universal agreement among the relevant studies that Yangon is vulnerable to these categories of hazard. The vulnerability of Yangon to each of these hazards is comprehensively covered in the documents reviewed, and their findings summarized in this report.

The development of a disaster risk management (DRM) program is an important component of resilience, and it is important to use the available data to advance disaster risk management through mitigation. In the context of this report, DRM consists of four areas: mitigation, preparedness, response, and recovery. Vulnerability Assessments can be used to develop any of the four areas. However, experience has shown that mitigation is by far the most cost-effective and functional approach to risk management. Various studies have confirmed that each dollar spent as part of mitigation leads to a multi-dollar reduction in future costs. Mitigation can comprise strengthening the existing built environment, mandatory implementation of robust building codes, and improved construction quality management.

ORGANIZATION OF THIS REPORT

This report is divided into eight chapters and includes an appendix. Chapter 2 presents a detailed discussion of the four natural hazards (earthquake, wind, flood, and fire) examined. Chapters 3 and 4 introduce the exposure environment in Yangon and the fragility functions for the built environment. This is followed by discussions on pre-event assessment methodology in Chapter 5 and post-event damage assessment in Chapter 6. Chapter 7 presents information on DRM and response. A discussion of relevant laws and regulations is presented in Chapter 8. Chapter 9 contains a brief discussion of building regulatory assessment and reform, intended as an initial discussion of the subsequent project on building regulatory resilience for the city. Chapter 10 presents a summary of findings and conclusions based on the analysis of available material.

The primary scope of this work is to review existing data, reports, and other supporting material that assesses the hazard, exposure and vulnerabilities of Myanmar against natural disasters and identify the gaps to increase resilience. Any conclusions, findings, and recommendations by the authors are presented as discussion points in the last section of each chapter.

ABOUT THIS REPORT

- The authors would like to note the following points regarding the materials presented in this report:
- In the past decade, a significant amount of work has been dedicated to various components of the structural Vulnerability Assessment (VA) of Yangon. Many international organizations have participated in various aspects of the assessment, focusing on different hazards or objectives. This report provides a review of the findings.
- Volume 1 serves as a reference document for the accompanying Volume 2: Analysis of research findings and implications on disaster resilience of Yangon's built environment, which presents a more detailed discussion of the report's conclusions and their application by city officials.
- To compile a detailed and comprehensive review, it was intended that the study include as many relevant reports and projects as possible. However, it is possible that some relevant contributions to this area might not have been included.
- The scope of work included a review of existing documents; no independent VA was conducted. However, during a visit to Myanmar in 2016, a walk through some of the townships served to confirm the vulnerability of the built environment noted by many authors, as well as the need to address this vulnerability.
- The material in each chapter of Volume 2 serves as a high-level summary of the findings and conclusions drawn by the original authors of the documents reviewed.
- The discussions section at the end of each chapter in Volume 2 includes an analysis of the documents reviewed and a summary of their importance for policymakers.
- At the time of writing, a number of active projects were underway in Yangon, at various stages of completion. Reports on these projects were therefore not available for inclusion. It is recommended that the material presented in this review be periodically updated to reflect the outcomes of those projects as results become available.

The following limitations are noted:

- The scope is limited to the review of existing reports; no independent investigation related to natural hazards and their impact on Yangon was undertaken.
- A number of relevant projects are still in progress at the time of writing. For these projects, final or even interim reports might not be available. In such cases, a brief description of the project scope and goals is presented.
- For a number of previous natural disasters, such as 2008's Cyclone Nargis, damage assessment data was not documented. If such data becomes available in the future, it could enrich the material presented in this report.
- Given the project scope, no detailed reviews of the existing permitting process or regulatory process are presented. However, based on the review of available hazard and vulnerability reports, recommendations relevant to this topic are included in this report.
- The report does not consider informal settlements in detail. However, since these components form an integral part of the city's fabric and contribute to its resilience, brief discussions on informal housing are included when available in the studies or accessible through independent web-based search.
- Finally, the area of study is limited to Yangon City. Yangon is comprised of four districts and 33 townships (see Figure 2). It is part of the larger Yangon Region, which has 12 additional townships (not included in this study).

Content

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MYANMAR MINISTRIES, DEPARTMENTS, AND ORGANIZATIONS

	ORGANIZATION	WEB ADDRESS
AMA	Association of Myanmar Architects	
CIDB	Construction Industry Development Board	
CQHP	Committee for Quality Control of High-Rise Building Construction Projects	www.cqhp.org
DDM	Department of Disaster Risk Management (Ministry of Social Welfare, Relief and Resettlement)	www.myanmar.gov.mm/en/ministry-of-social-welfare-relief-resettlement
DHSHD	Department of Human Settlement and Housing Development	
DMH	Department of Meteorology and Hydrology (Ministry of Transport and Communications)	www.motc.gov.qa
DMTC	Disaster Management Training Centre	
DOP	Department of Population (Ministry of Labour, Immigration and Population)	www.dop.gov.mm
DUHD	Department of Urban and Housing Development (Ministry of Construction)	
EDB	Engineering Department (Buildings) (Yangon City Development Committee)	www.ycdc.gov.mm
EDRB	Engineering Department (Roads and Bridges) (Yangon City Development Committee)	www.ycdc.gov.mm
FSD	Fire Services Department	www.fsd.gov.mm
GAD	General Administrative Department	www.gad.gov.mm
GUM	Government of the Union of Myanmar	
HIC	High-Rise Inspection Committee	
MCCDDM	Myanmar Consortium for Capacity Development on Disaster Management	
MEngC	Myanmar Engineering Council	www.myanmarengc.org
MEC	Myanmar Earthquake Committee	
MCEA	Federation of Myanmar Construction Entrepreneurs Association	www.mceamyanmar.org
MES	Federation of Myanmar Engineering Society	www.mes.org.mm
MGS	Myanmar Geosciences Society	www.myanmargeosciences.org

MHA	Ministry of Home Affairs	www.myanmarmoha.org
MIMU	Myanmar Information Management Unit	www.themimu.info
MMA	Myanmar Medical Association	www.mmacentral.org
MNSN	Myanmar National Seismic Network (code MM)	www.fdsn.org/networks/detail/MM
MOC	Ministry of Construction	www.construction.gov.mm
MoHS	Ministry of Health and Sports	www.mohs.gov.mm
MPD	Myanmar Private Sector Disaster Management Network	
MRCS	Myanmar Red Cross Society	www.redcross.org.mm
MRESA	Myanmar Real Estate Service Association	www.myanmar-mresa.com
MSWRR	Ministry of Social Welfare, Relief and Resettlement	www.mswrr.gov.mm
NDMC	National Disaster Management Committee	
UMFCCI	Union of Myanmar Federation of Chambers of Commerce and Industry	www.umfcci.com.mm
UY	University of Yangon	www.uy.edu.mm
YCDC	Yangon City Development Committee	www.ycdc.gov.mm
YEB	Yangon Electricity Board	
YGH	Yangon General Hospital	www.yghhealthcare.org
YHT	Yangon Heritage Trust	www.yangonheritagetrust.org
YTU	Yangon Technological University	www.ytu.edu.mm

INTERNATIONAL ORGANIZATIONS

	ORGANIZATION	WEB ADDRESS
ACI	American Concrete Institute	www.concrete.org
ADB	Asian Development Bank	www.adb.org
ADPC	Asian Disaster Preparedness Center	www.adpc.net
AFD	Agence Française de Développement (French Development Agency)	www.afd.fr
ASCE	American Society of Civil Engineers	www.asce.org
ASEAN	Association of Southeast Asian Nations	www.asean.org
ASTM	ASTM	www.astm.org
ATC	Applied Technology Council	www.atcouncil.org
CFE-DM	Center for Excellence in Disaster Management and Humanitarian Assistance	www.cfe-dmha.org
DFID	Department for International Development	www.gov.uk/government/organisations/department-for-international-development
ECHO	European Civil Protection and Humanitarian Aid Operations	www.ec.europa.eu/echo/index_en
EERI	Earthquake Engineering Research Institute	www.eeri.org
EOS	Earth Observatory of Singapore	www.earthobservatory.sg
FEMA	Federal Emergency Management Agency	www.fema.gov
GEM	Global Earthquake Model	www.globalquakemodel.org
GFDRR	Global Facility for Disaster Reduction and Recovery	www.gfdrr.org
GGS	Grant for Global Sustainability	www.unu.edu/projects/grant-for-global-sustainability-ggs.html
HARP	Humanitarian Assistance and Resilience Programme	www.harpfacility.com
HCT	Humanitarian Country Team	
IAFSS	The International Association for Fire Safety Science	www.iafss.org
IFC	International Finance Corporation	www.ifc.org
JICA	Japan International Cooperation Agency	www.jica.go.jp
KOICA	Korea International Cooperation Agency	www.koica.go.kr
	Kyoto University	www.kyoto-u.ac.jp

MTU	Mandalay Technological University	www.mtu.edu.mm
NFPA	National Fire Protection Association	www.nfpa.org
NIWA	National Institute of Water and Atmospheric Research Ltd	www.niwa.co.nz
NOAA-HRD	Hurricane Research Division of National Oceanic and Atmospheric Administration	www.aoml.noaa.gov/hrd/
NOAA-JTWC	Joint Typhoon Warning Center of National Oceanic and Atmospheric Administration	www.pzal.ndbc.noaa.gov/collab/jtwc/
OCHA	United Nations Office for the Coordination of Humanitarian Affairs	www.unocha.org
PEER	Pacific Earthquake Engineering Research	www.peer.berkeley.edu
	Plan International	www.planusa.org
RFA	Radio Free Asia	www.rfa.org
RHDHV	Royal HaskoningDHV	www.royalhaskoningdhv.com
SATREPS	Science and Technology Research Partnership for Sustainable Development	www.jst.go.jp
SDC	Swiss Agency for Development and Cooperation	www.eda.admin.ch/sdc
UNDP	United Nations Development Programme	www.undp.org
UNEP	United Nations Environment Programme	www.unenvironment.org
UN-Habitat	United Nations Human Settlements Programme	www.unhabitat.org
UNU	United Nations University	www.unu.edu
USAID	U.S. Agency for International Development	www.usaid.gov
USGS	United States Geological Survey	www.usgs.gov
WB	World Bank	www.worldbank.org
WHE	World Housing Encyclopedia	www.world-housing.net

ACRONYMS, ABBREVIATIONS, AND NOTATIONS

BCC	Building Completion Certificates
BE	Bachelor of Engineering
BM	brick masonry
BN	brick-noggin
BRCA	Building Regulatory Capacity Assessment
BT	bamboo or timber
CBD	Central Business District
DE	design earthquake
DoM	Departments of Myanmar
DRM	disaster risk management
DRR	disaster risk response
DS	damage state
FRA	fire risk assessment
ft	feet
g	gravity
GIS	Geographic Information System
GPS	Global Positioning System
h	hour
LiDAR	Light Detection and Ranging
km	kilometer
Ksi	1000 lb force per square in.
m	meter
mm	millimeter
M	magnitude
MAPDRR	Myanmar Action Plan on Disaster Risk Reduction
MCE	maximum considered earthquake
MMK	Burmese kyat
MNBC	Myanmar National Building Code
MPa	Mega Pascal
mph	miles per hour
PE	Professional Engineer
PGA	peak ground acceleration
PGV	peak ground velocity
RC	reinforced concrete
RDA	rapid damage assessment
RE	Registered Engineer
RSE	Registered Senior Engineer
RVA	rapid vulnerability assessment
RVS	rapid visual screening
S1	1-second spectral acceleration
Sa	short spectral acceleration
SS	short-period spectral acceleration
sec	second
Tr	Return period
UAV	unmanned aerial vehicle
URM	unreinforced masonry
USA	United States of America
VA	vulnerability assessment
VS	Visual Screening/Survey

1. Introduction

1.1 OVERVIEW

Annualized losses from natural disasters are equivalent to almost 1 percent of Myanmar's total gross domestic product[6], making it one of the world's most vulnerable countries to natural disasters.

Yangon is the most susceptible of Myanmar's cities to economic losses associated with disasters. The Yangon Region, in which the city is located, is also considered very vulnerable to a number of natural hazards, as described later.

FIGURE 1. Natural disaster vulnerability map for the country (MIMU, 2015)

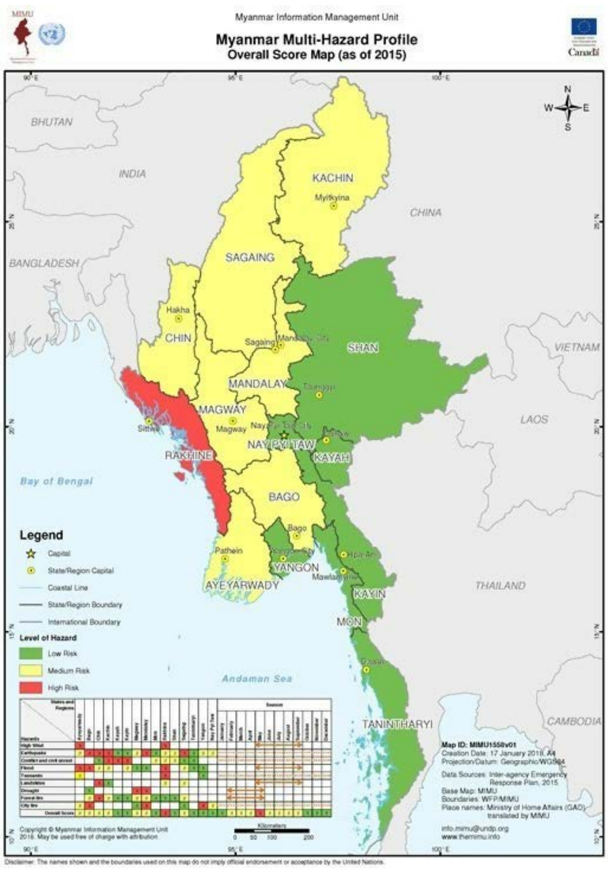


Figure 1 (Myanmar Information Management Unit (MIMU), 2015) illustrates the country's multi-hazard profile.

The fast-growing and strategically located city of Yangon has a population of over five million people, is strategically located, and it is the country's largest city, its financial capital, and an engine of economic growth. Tourism is a major industry for the city: currently, over one million people visit Yangon annually. One of the key attractions of Yangon is its rich architectural heritage, with many historical buildings and religious structures. This heritage has been preserved largely due to slow development over the years. Yangon's built environment is vulnerable to a number of natural hazards, including earthquakes, floods (both natural and man-made), windstorms (notably cyclones), and fire, all of which have caused damage to its structures in the past.

SEISMIC HAZARDS: The Yangon Region, in which the city is located, is also considered very vulnerable to a number of natural hazards, as described later. The Sagaing fault, running north-south through the country, is located approximately 35km east of the city. In 1930, a magnitude 7.3 earthquake struck Myanmar—the largest earthquake to impact Yangon to date. With the epicenter 75km from the city, the earthquake resulted in an estimated 50 fatalities in Yangon, damaging many buildings including the General Post Office and Railway Headquarters[7], and caused approximately 500 casualties countrywide[8]. Given the vulnerability of the built environment, an earthquake of similar magnitude and with an epicenter closer to the city could have devastating consequences today.

6. (GFDRR, 2012)
7. Brown et al., 1933
8. Myanmar Times, 2016

STORMS: The city is geographically close to the Andaman Sea and the Bay of Bengal, and thus susceptible to tropical storms and high winds. In 2008, Cyclone Nargis, the worst natural disaster in the history of the country, resulted in 1,640 fatalities in the city and 140,000 countrywide, mainly in the delta region, causing over $10 billion in damages. The Yangon Region, among four others, was declared a disaster area -284 temples were destroyed in this region alone. The cyclone damage was caused by high wind speeds, heavy rain, and storm surge, resulting in widespread flooding[9].

FLOODING: Flooding is a common occurrence for the country and the city. It can be caused by natural events, including (i) heavy rainfalls and tropical storms during monsoon seasons, (ii) flooding rivers (the city is surrounded by a number of rivers), and (iii) high tides—or by man-made factors such as the city's antiquated drainage system, which can become clogged and unable to properly drain rainwater. Annual floods have resulted in damage to both buildings and agriculture. During the 2018 monsoon season, flooding occurred in many residential townships within the city due to heavy rain, high tides, and high river levels, causing fatalities and damage to buildings.

FIRES: Between 200 and 300 fires break out annually in the Yangon Region, which is classified as a high-risk zone for fire[10]. Many factors contribute to the prevalence of fires in city, including congested housing, indoor electrical deficiencies, and the use of fuel indoors. In 2005, for example, a fire affected over 9,000 people and caused damage totaling over US$50,000[11]. A 2017 fire destroyed the iconic Kandawgyi Palace Hotel, primarily constructed of teak, in traditional Burmese style, resulting in fatalities and injuries.

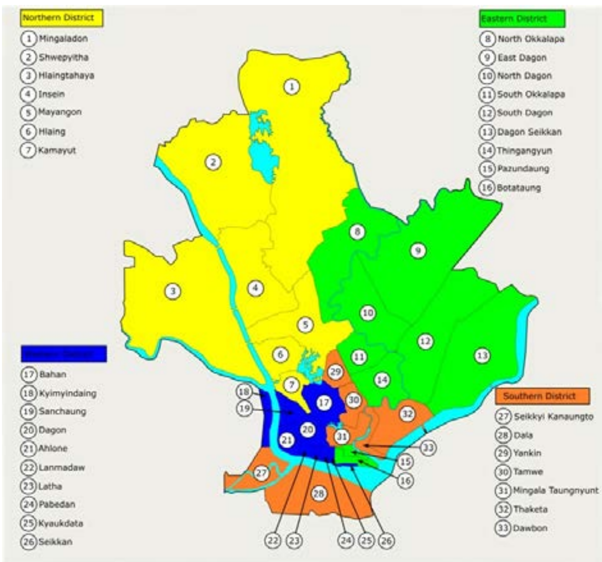
The vulnerability of the city to natural disasters is exacerbated by several factors, including:

> Many buildings were constructed in the late 19th century and designed based on British Standards and Codes. As such, there was scant knowledge of seismic and wind hazards, and minimal provisions to design for them. The exposure vulnerability is amplified because of the ongoing importance of these buildings and their large number of occupants.

While a robust building code has been developed by qualified Myanmar engineers based on internationally recognized standards, such as the American Society of Civil Engineers (ASCE) 7[12], the code provisions have not yet been adopted into the law. The code has provisions for natural hazards, such as earthquakes and wind, as part of the structural sections. In addition, fire safety measures, e.g. sprinkler spacing and minimum cover for fire rating, are listed in the architectural sections. However, as it stands, there is no legal mandate for regulation and enforcement. The city also has no means for residents to apply for permits and submit plans electronically; electronic permitting and plan checks are under consideration for implementation in the near future.

The city's population has been increasing rapidly: as is typical in many developing countries, internal migration to urban areas by people looking for better economic opportunities has led to housing shortages. In addition, the lack of available housing and finances has led to the development of informal settlements. These typically self-built units lack many traditional structural safety features; when residents have limited financial resources, other improvements take priority over strengthening measures.

FIGURE 2. Map of Yangon districts and townships (YCDC 2019)



9. United Nations Environment Programme (UNEP), 2009
10. MIMU, 2015
11. United Nations Human Settlements Programme (UN-Habitat), 2011
12. ASCE, 2006

2. Natural hazards in Yangon

2.1 INTRODUCTION

Determining the intensity of likely natural hazards is a key prerequisite for conducting vulnerability analyses of built environments.

To quantify and compare relative risk, both a method and a metric need to be developed. Deterministic and probabilistic hazard metrics are commonly utilized for this purpose. For example, to detect earthquake hazard, the deterministic hazard could be the maximum magnitude earthquake possible from a given fault, whereas probabilistic approaches for earthquake hazard identification considers aggregation and the probability of different magnitudes from various faults. In the probabilistic realm, expected values for the city can be established. For example, a natural hazard return period such as a 475-year earthquake and a 100-year flood can be specified, and the expected intensity of the hazard for these events determined.

Key findings and results from the review of sources related to natural hazards affecting the city of Yangon are summarized in this section. Although four natural hazards - earthquake, wind, flood, and fire - are discussed, the sections on earthquake and flood include significantly more documents, because these hazards have a larger impact on the city and are thus studied in more detail.

2.2 EARTHQUAKE HAZARD

2.21 OVERVIEW

Significant research has been undertaken in Yangon to establish and disseminate a seismic hazard profile for the city.

Although the city has not experienced a large earthquake for over 80 years, the significance of this category of hazard cannot be underestimated. Both Port-au-Prince, Haiti, and Katmandu, Nepal, had not experienced any major earthquakes for many decades before they were struck by moderate-major events in 2010 and 2015, respectively. These events resulted in a large number of fatalities and collapsed buildings.

The earthquake hazard is particularly acute for a number of townships in Yangon where buildings are constructed on soft landfills near the river. Seismic waves attenuate as they propagate from the earthquake epicenter. However, soft underlying soil tends to amplify the ground motion, resulting in larger motions and larger forces imparted on buildings. Non-ductile buildings constructed without the ability to absorb these amplified motions safely can sustain damage or even collapse.

Earthquake hazards at a site can result from several underlying factors, including: (i) ground motion, (ii) site liquefaction, (iii) landslide and lateral spreading, and (iv) ground displacement. Given the topology of the city and its distance from the governing fault, the latter two hazards do not apply. However, both ground shaking and liquefaction must be considered.

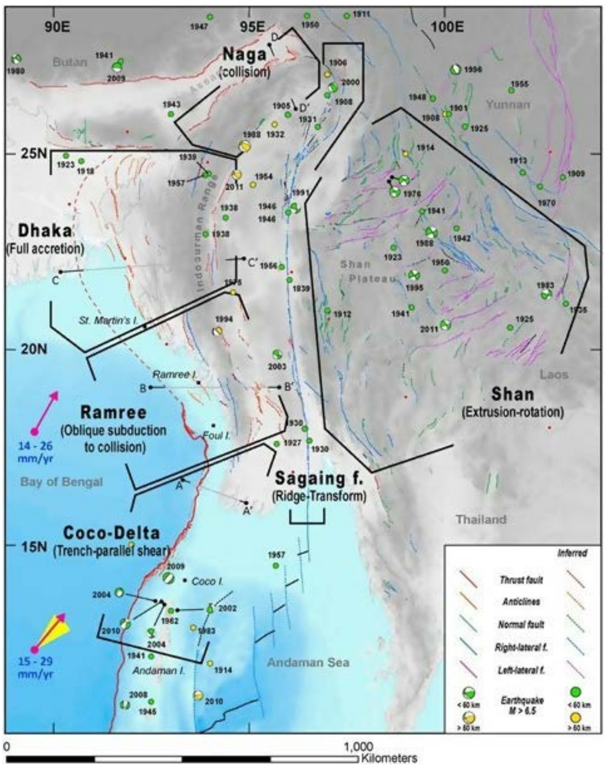
2.22 HISTORIC EVENTS AND PLATE TECTONICS

Earthquakes affecting the city of Yangon primarily occur along the 1,000-km-long Sagaing fault.

The western part - the Indian plate - moves northward relative to the eastern half of the Eurasian plate at a rate of approximately 24mm/year. This is a strike-slip, right lateral fault, which is similar in mechanism, length, and slip rate to the well-known San Andreas Fault in California. A list of historical earthquakes in the area is presented by Wang et al. (2014) in Figure 3. In addition to this fault, a number of other faults are also present that can impact the study area, as discussed by Tun et al. (2012) (see Figure 4).

Swe (2018) studied the renovation records of five pagodas to establish a list of the historic earthquakes in the Yangon-Bago areas (see Figure 5). As shown, a significant earthquake could be anticipated approximately every 100 years. The authors also studied scenario earthquakes and determined that the PGA for a M7.0 earthquake would result in PGA of 0.2–0.3 g for hard underlying soil in Yangon.

FIGURE 3. Sagaing fault and historic destructive earthquakes (Wang et al., 2014)



Tun (2015) chronicles a list of major earthquakes in Myanmar based on a study of historical records; a portion of a Table from this report relevant to Yangon is summarized in Table 1.

In 1930, a M7.3 earthquake resulted in fatalities and structural damage in the city of Yangon. In 2017, a M5.1 earthquake occurred approximately 70 km from the city. The Taikkyi Township was hit the hardest. There were two fatalities and 36 injuries within a residential quarter, and several temples were damaged (United States Geological Survey (USGS), 2019).

Wang et al. (2011) studied the seismic potential of the southern Sagaing fault. This section of the fault did not fail during the 1930 event. In addition, local villagers were interviewed and claimed that they had only experienced two or three earthquakes in their lifetime. The authors concluded that this section of the fault appeared to have been locked and would therefore be a potential area for the occurrence of the next major earthquake, producing an event of M7 or greater along its 50-km length. The authors also determined that there were two distinct segments of the fault, which together produce return times for destructive earthquakes of every 100–200 years (see Figure 6).

Aung (2015) notes that earthquakes have had an impact on Yangon for close to 100 years, including the M7.0 1927 earthquake and the M5.7 1978 earthquake. According to the authors, these events point to the existence of a blind fault underneath the soft sediments of the Yangon Region. Earthquakes in Yangon could occur due to rupture of this fault. Thein (2015) listed the major seismic events in Myanmar, as summarized in Table 2; note that the country has experienced a massive event every 200 years and a large earthquake every decade.

FIGURE 4. Faults in southern central Myanmar (Tun et al., 2012)

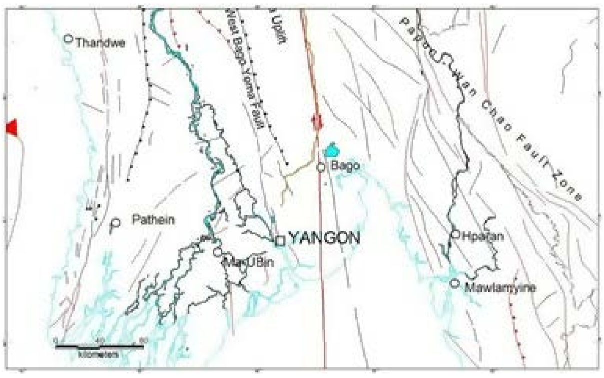


TABLE 1: **Historic earthquakes affecting Yangon taken from Tun, 2015.**

DATE	LOCATION	M AND/OR BRIEF DESCRIPTION
July 23, 1884	Yangon	
September 10, 1927	Yangon	
December 17, 1927	Yangon	M7; extended to Dedaye
March 27, 1931	Yangon	
May 16, 1931	Yangon	
May 21, 1931	Yangon	

TABLE 2. **Catalog of earthquakes in Myanmar (Thein, 2015)**

TYPE OF EARTHQUAKE	MW	FREQUENCY	TIME RANGE
Great	> 8	1	1839–2011
Major	7–7.9	16	1839–2011
Strong	6–6.9	47	1950–2011
Moderate	5–5.9	09	1950–2011

FIGURE 5. Earthquakes in the Yangon-Bago area (Swe, 2018)

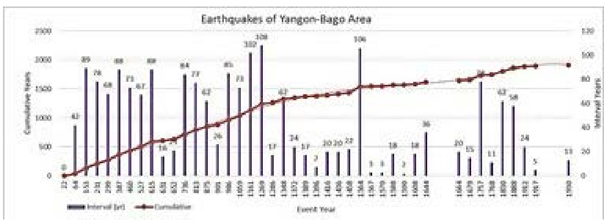
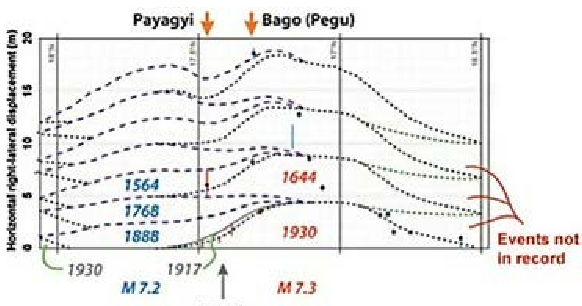


FIGURE 6. Classis uniform slip model for the southern Sagaing fault (Wang et al., 2011)



2.2.3 GEOTECHNICAL AND SITE CONDITIONS

Site conditions can have a significant effect on the motion generated by an earthquake.

To support the development of seismic hazard maps for Yangon, UN-Habitat et al. (2015) conducted geotechnical investigations for the city. The report concluded that the main soil types for the city are Hlawga shale, Thadugan sandstone, Besapet alternation, Arzanigon sandrock, Danyingon clay, valley-filled deposits, and recent alluvium (see Figure 7). This is consistent with findings by other researchers (see section 2.2.4).

The site class is typically based on the average shear velocity in the top 30m of soil at a location. There are several methods in computing the shear wave velocity at 30 m (VS, 30). San et al. (2018) collected borehole (log of boring) data for Yangon and then used standard penetration test values (blow count) to develop the site class map for the city. Data from more than 500 boreholes in 23 of the townships were obtained from YCDC or the construction industry. Data from 159 suitable samples were used for analysis (see Figure 8). The data were then synthesized, and average shear velocities for the selected boreholes at various depths were tabulated. The contours of VS, 30 values for Yangon were then developed, as shown in Figure 8.

FIGURE 7. Geological map of the study region (UN-Habitat et al., 2015)

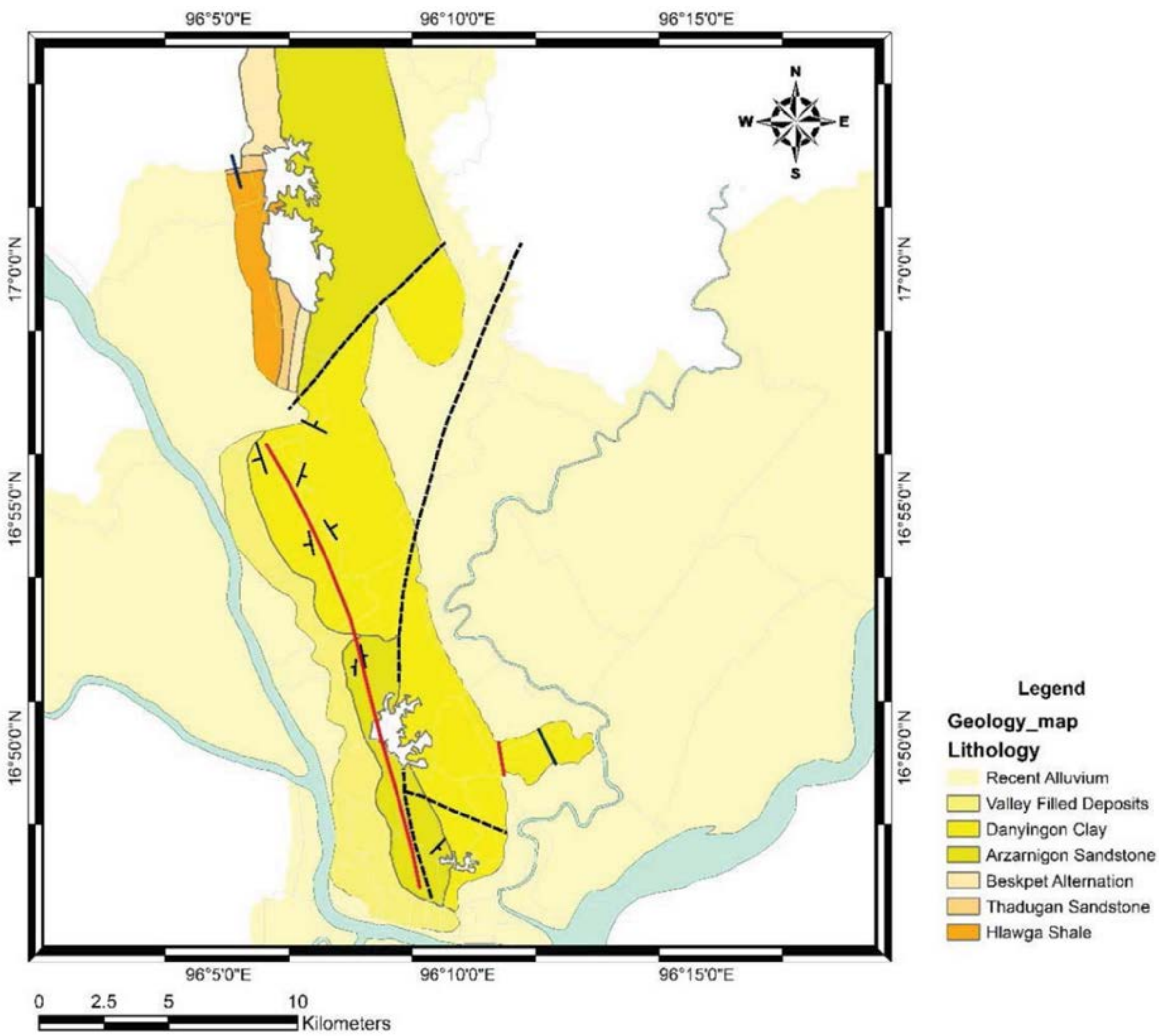
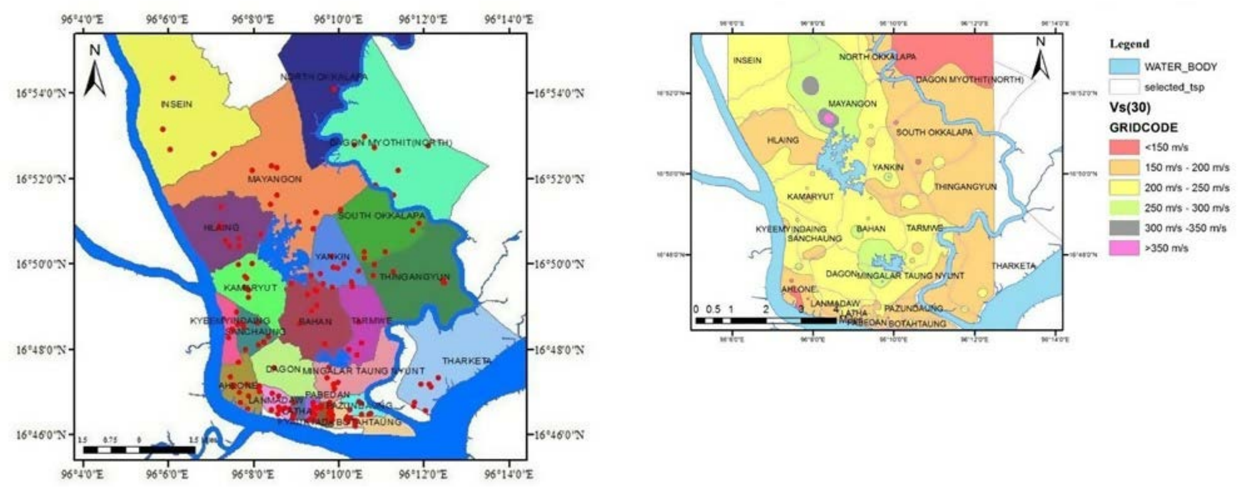


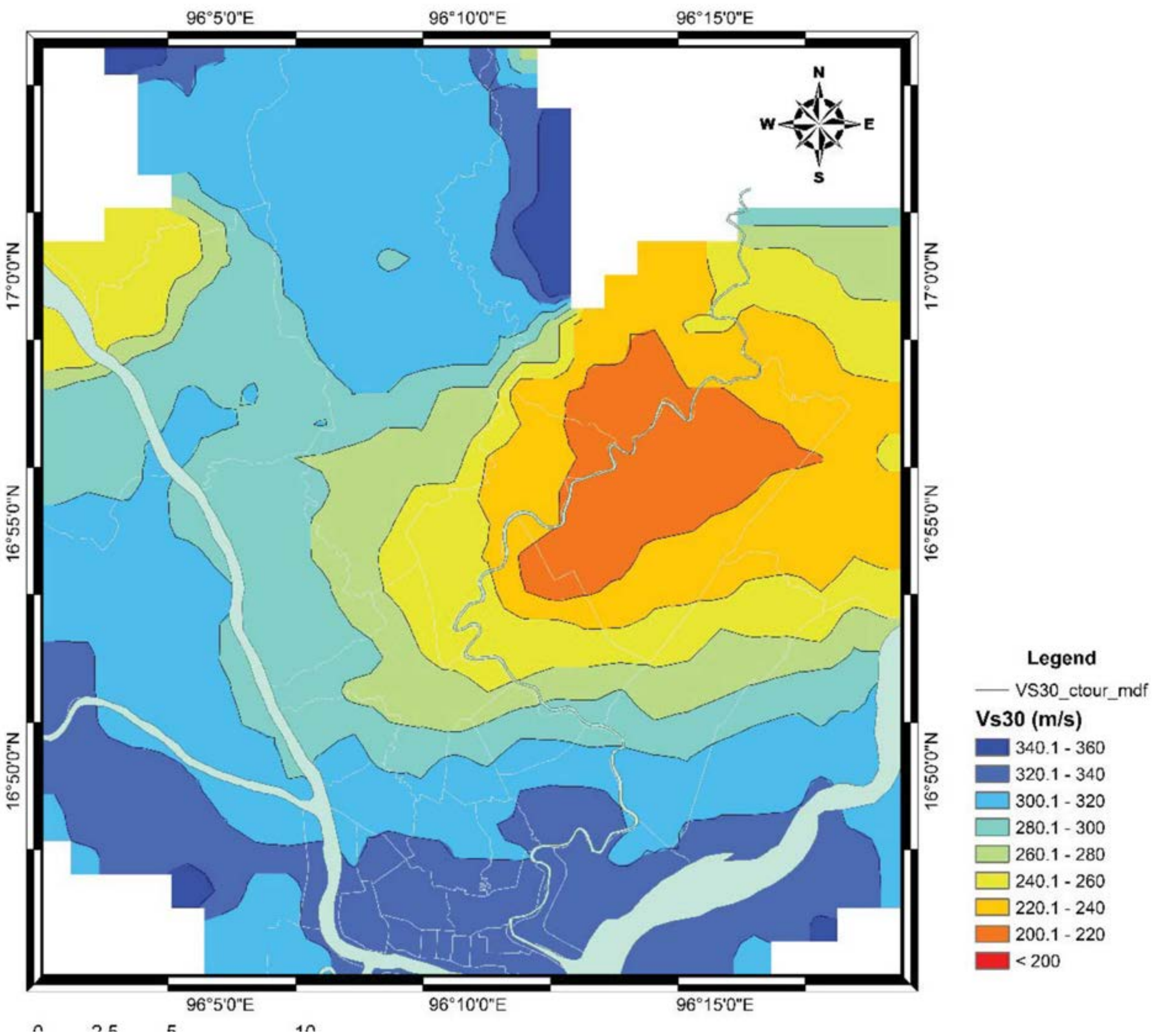
FIGURE 8. Determination of site condition for Yangon (San et al., 2018).



Locations of boreholes

Average 30-m shear velocities

FIGURE 9. Shear velocity profile of the study region (UN-Habitat et al., 2015)



As part of developing a probabilistic seismic hazard map for Yangon, UN-Habitat et al. (2015) developed the VS, 30 profile map for the city (see Figure 9).

Table 3 presents the threshold values for site class definition reproduced from ASCE 7, the basis of seismic design for many countries, including Myanmar. Most of the city can be classified as site class D, with large areas of site class E, especially close to rivers and in the downtown area. Accordingly, major amplification of earthquake shaking is anticipated in the city due to the underlying soil profile.

2.2.4 LIQUEFACTION POTENTIAL

There is potential for significant liquefaction in Yangon's downtown townships in the event of an earthquake.

Tint et al. (2018) studied the liquefaction potential for the Yangon downtown area. They noted that downtown is covered by the valley-dilled deposit and younger alluvium soil (Figure 10). The authors collected data from 67 boreholes in the study area and developed the liquefaction potential index for scenario earthquakes. Figure 10 presents the liquefaction potential map for the city for a 475-year return period (10 percent in 50 years) earthquake.

This corresponds to a M7.5 event with a PGA of 0.25g, of similar magnitude to the 1930 earthquake. Note that liquefaction is spread over a large area of downtown with potential for severe liquefaction concentrated in two townships. For a rare earthquake of M7.9 (possible for Yangon), the entire area of the six townships shown in Figure 10 could experience significant liquefaction.

2.2.5 SEISMIC HAZARD PARAMETERS FOR YANGON

Swe (2004) and Thein et al. (2006) developed the PGA for the Yangon area. The authors examined geological features, faulting, and historical data and estimated with 95 percent confidence that significant earthquakes affecting the city of Yangon have an approximate mean and standard deviation of 70 and 30 years, respectively. The authors then estimated PGA for Yangon and developed seismic zonation for the city and surrounding areas.

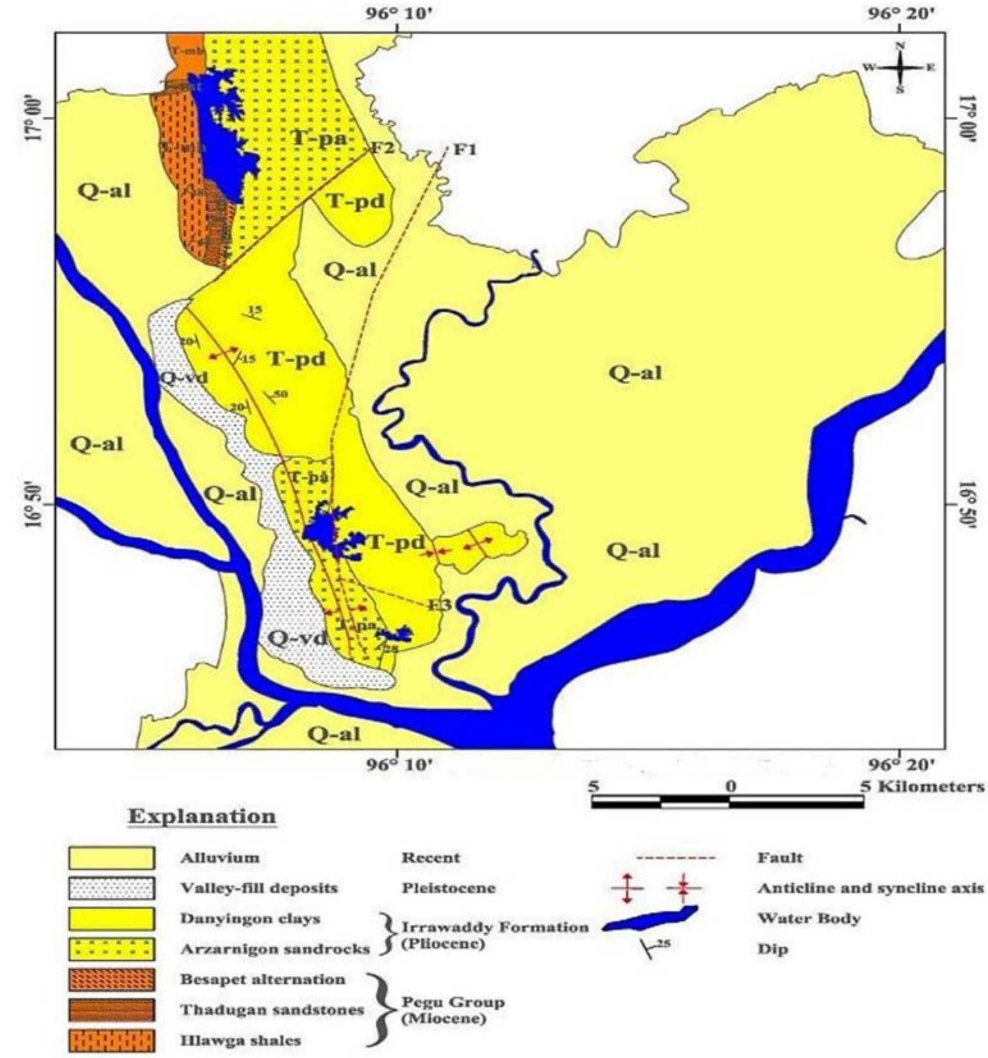
MEC (2005) published the deterministic hazard zonation map for Myanmar. The portion of map relevant to Yangon is presented in Figure 11. Note that Yangon falls into the moderate to strong zonation.

Thant (2012) developed probabilistic seismic hazard maps for Myanmar by studying the records of damage to pagodas to identify historic earthquakes. The distribution of PGA and peak ground velocity (PGV) for the 475-year event is presented in Figure 12. The figures are adopted from Thant (2012) but truncated to focus on the Yangon Region. The PGA and PGV in Yangon are approximately 0.2–0.3 g and 30–45 cm/sec, respectively. Site amplification is not included in the figures. Thus, for a designlevel earthquake, significant ground shaking and velocity can be anticipated in Yangon. Using probabilistic methodology, Thant (2012) developed the probabilistic seismic hazard map for the Yangon Region; PGA, and spectral acceleration maps for the region were developed for both 475-year and 2475-year events. It is noted that 475-year PGA for the Yangon Region is 0.2–0.5 g.

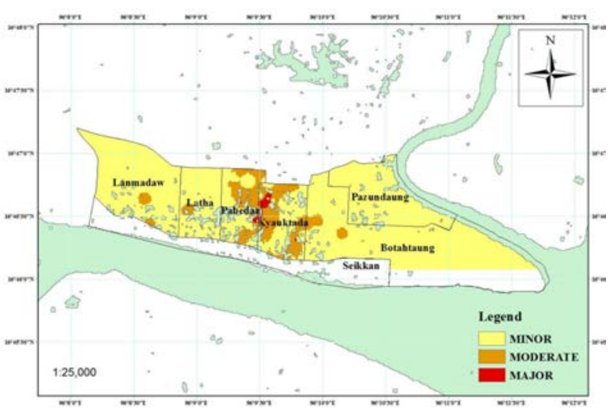
TABLE 3. Site class classification per ASCE 7

SITE CLASS	PROFILE	VS,30, M/SEC
A	Hard rock	> 1,500
B	Rock	> 760
C	Very dense soil and soft rock	> 360
D	Stiff soil	> 180
E	Soft clay soil	< 180
F	Liquefiable soil	--

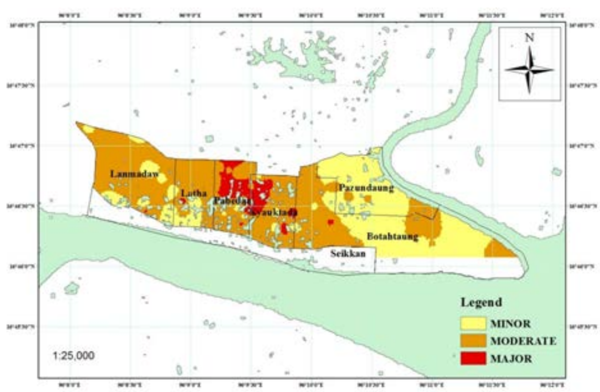
FIGURE 10. Development of liquefaction map of Yangon (Tint et al., 2018)



Geological map

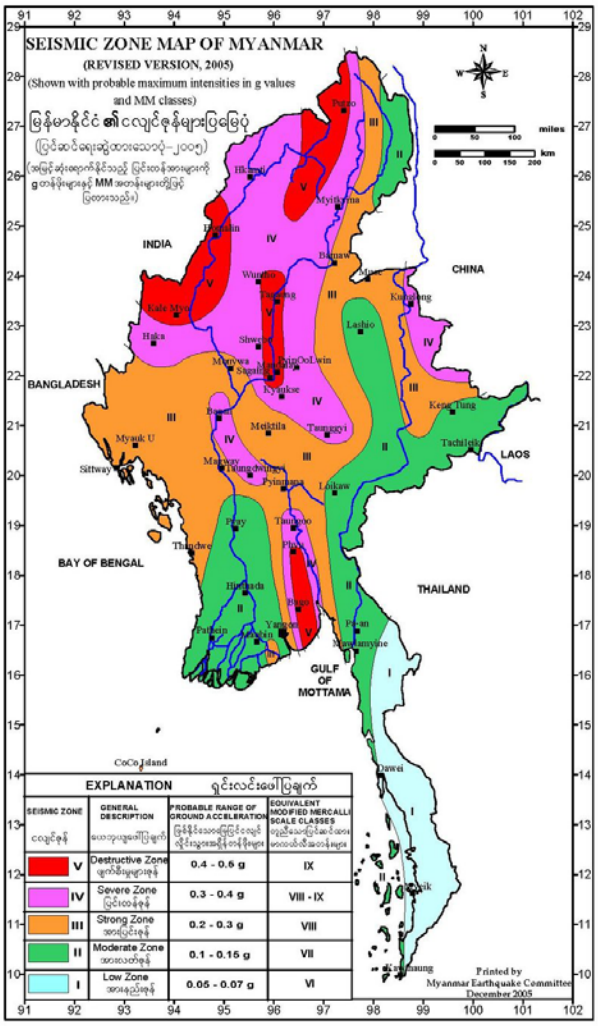


475-year liquefaction



2475-year liquefaction

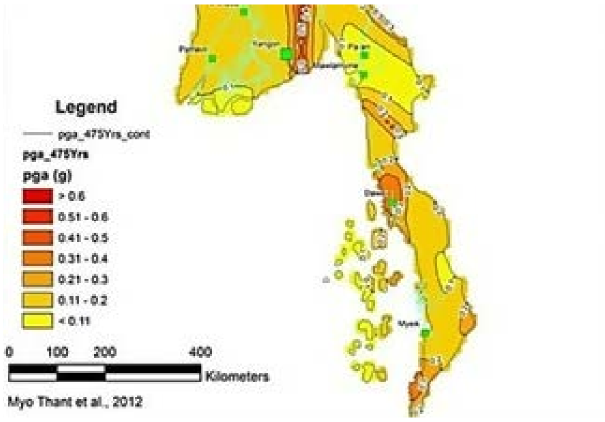
FIGURE 11. Seismic hazard zonation (MEC, 2005)



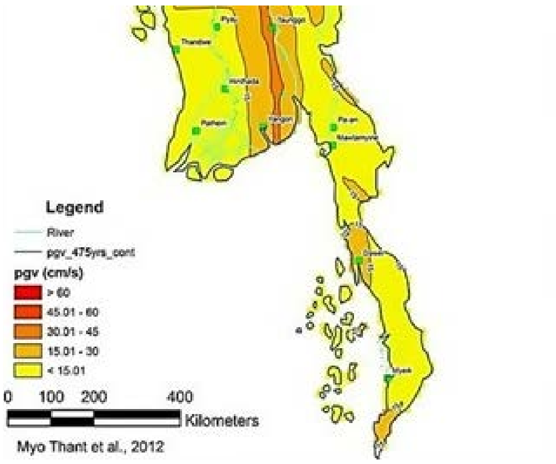
Revised by Dr. Maung Thein, U Tint Lwin Swe and Dr. Sone Han (December 2005)

Deterministic

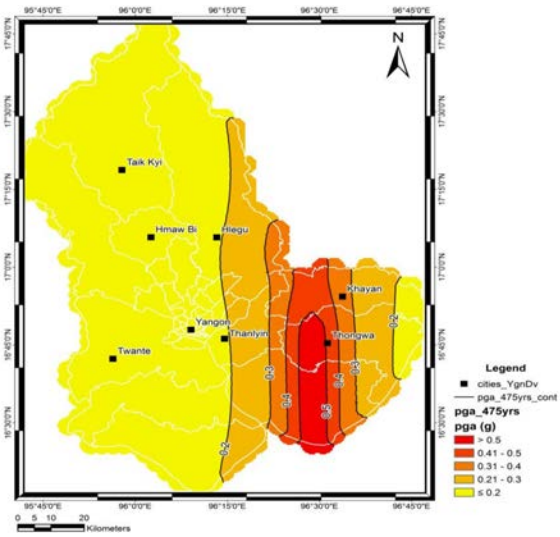
FIGURE 12. 475-year event hazard distribution for Myanmar and Yangon (Thant, 2012)



PGA



PGV



PGA, Yangon Region

FIGURE 13. Bedrock 475-year spectral accelerations (Htwe et al., 2010)

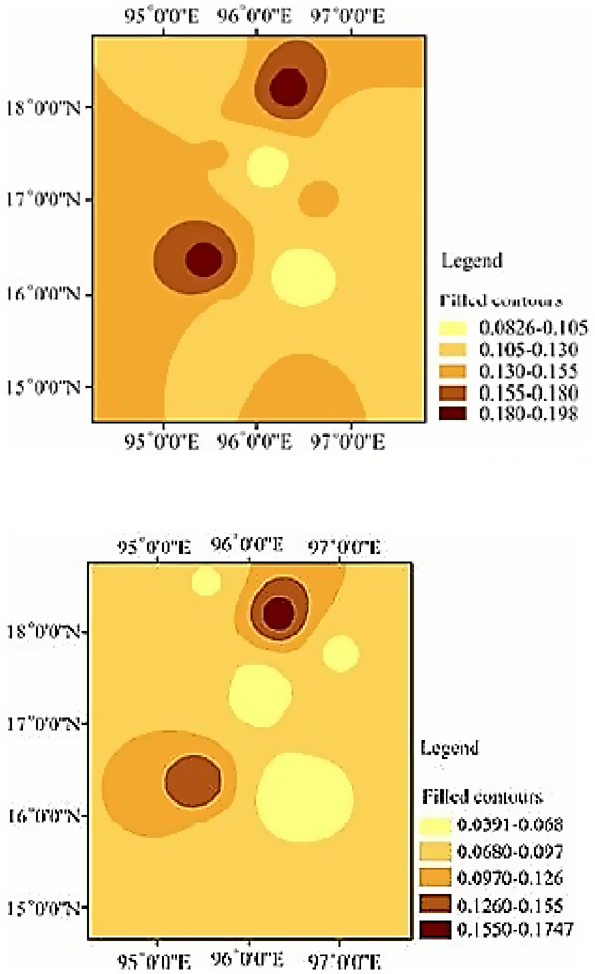
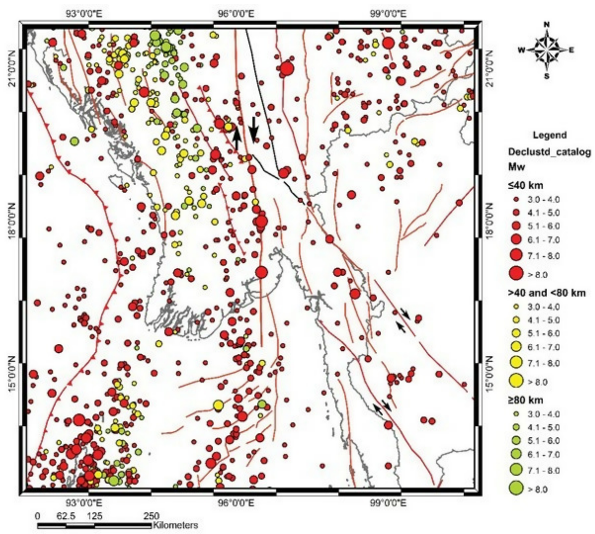


FIGURE 14. Seismicity activity and faults in Yangon Region (UN-Habitat et al., 2015)



Htwe et al. (2010) developed seismic hazard maps for Yangon. The study area focused on nine source zones centered on Yangon, with a radius of about 200 km. Using various sources and attenuation relations, the authors developed the bedrock spectral accelerations for the area of study for both 475-year and 2475-year events. The bedrock spectral accelerations for the 475-year event are shown in Figure 13. It is noted that site amplification needs to be applied to the spectral acceleration values to account for the soil amplification.

UN-Habitat et al. (2015) carried out a probabilistic seismic hazard assessment for Yangon. The authors studied the seismicity of the region and its active faults (Figure 14). Using a statistical method based on the location, the number of active faults, the probability of a given magnitude earthquake occurring along a given fault, and the recently developed ground motion attenuation relations developed as part of the Pacific Earthquake Engineering Research (PEER) Center's strong motion program (PEER, 2019a), the authors developed the probabilistic seismic hazard parameters for Yangon.

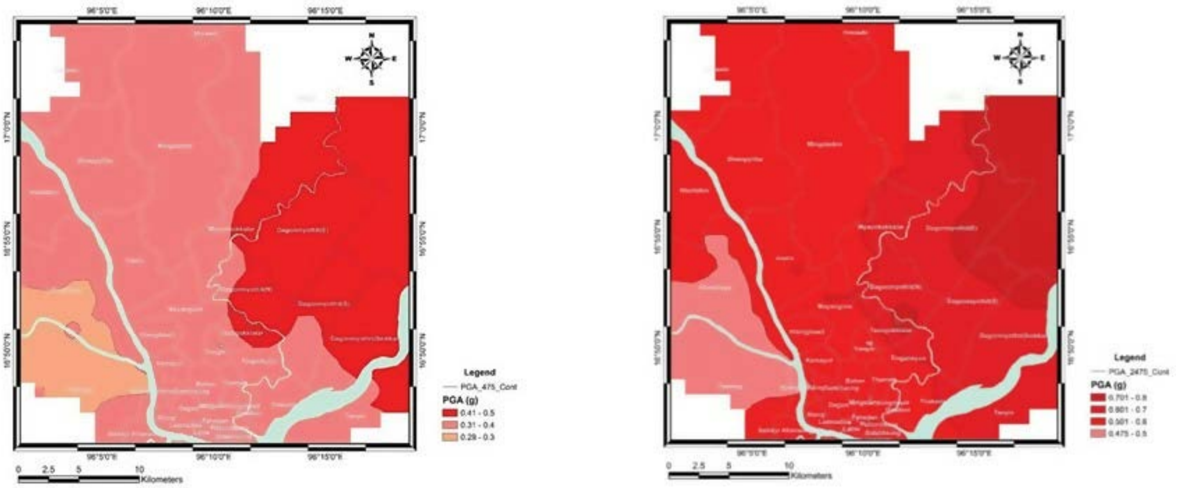
The probabilistic seismic hazard maps for the city were developed for two levels of seismicity:

- 475-year event (10 percent in 50 years). This is a strong earthquake, referred to as a design earthquake (DE), and is the implicit level of seismicity used in modern building codes (such as ASCE 7 and Myanmar National Building Code (MNBC) 2016).
- 2475-year event (2 percent in 50 years). This is a rare and very strong earthquake, referred to as a maximum considered earthquake (MCE).

The PGA, short (0.2 sec) spectral acceleration (Sa), short-period spectral acceleration (SS), and 1-sec spectral acceleration (S1) are presented in Figure 15. For the 475-year event, typical PGA, SS, and S1 values for the city are 0.4, 0.7, and 0.5 g, respectively.

Somsa-Ard et al. (2013) examined both the probabilistic and deterministic seismic hazard for Myanmar. The PGA data are presented in Figure 16. Note that for Yangon, the deterministic PGA of 0.3–0.4 g is similar to the DE values. The probabilistic value of approximately 0.2 g does not include site amplification.

FIGURE 15. **Distribution of seismic hazard parameters (UN-Habitat et al., 2015)**



PGA

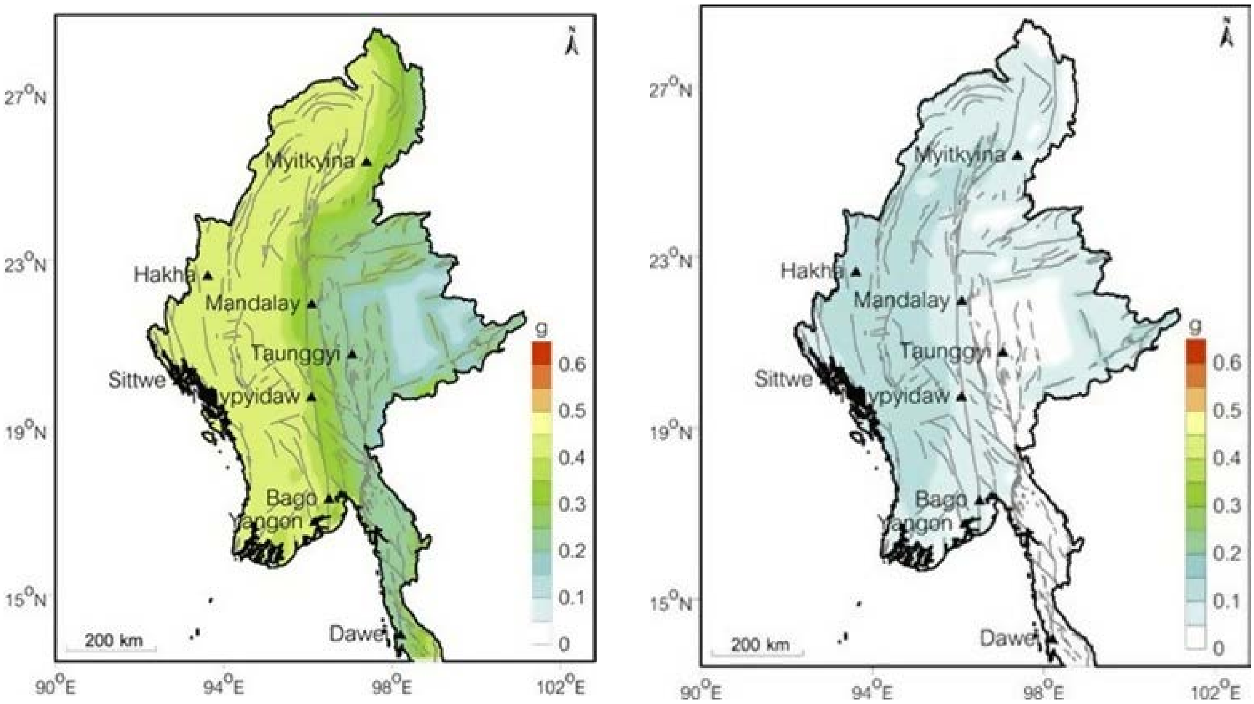
S_S

S_2

475-year event

2475-year event

FIGURE 16. **Deterministic and probabilistic PGA (Somsa-Ard et al., 2013)**



Deterministic

Probabilistic (475-year)

2.26 STRONG MOTION STATIONS

In recent years, there have been several initiatives to improve Myanmar's seismographic capacity.

Eight broadband seismographs have been installed by the Myanmar Government, China Earthquake Administration, Yunnan Seismic Bureau, and Regional Integrated Multi-Hazard Early Warning System for Africa and Asia.[13] In addition, two digital broadband seismographs were installed by the Department of Meteorology and Hydrology (DMH), and three analog seismographs were installed by JICA. While, some of these stations were not in operation in 2015, there has since been a major update to the strong motion and early warning system.

The Myanmar National Seismic Network (MNSN) has been installing and operating strong motion stations in Myanmar in recent years. Figure 17 and Table 4 present information regarding the location of some of the sensors from the DMH website (MNSN, 2019). These sensors successfully recorded strong motion data from the 2016 earthquake north of Mandalay.

The Earth Observatory of Singapore (EOS) has installed 30 strong motion stations in the country, the locations of which are shown in Figure 18[14]. At each location, a seismometer measuring velocity is placed 3m below ground to reduce interference from ambient noise. Data is processed in real time, and a trigger is set to react to a magnitude of approximately 1.5 or higher on the Richter scale. This data was used to develop shake maps after earthquakes, a process similar to the one used by USGS in the US.

A network of 21 strong motion stations across Myanmar is operated by the DMH, and data are used to issue alarms regarding earthquakes and tsunamis (Nature, 2019).

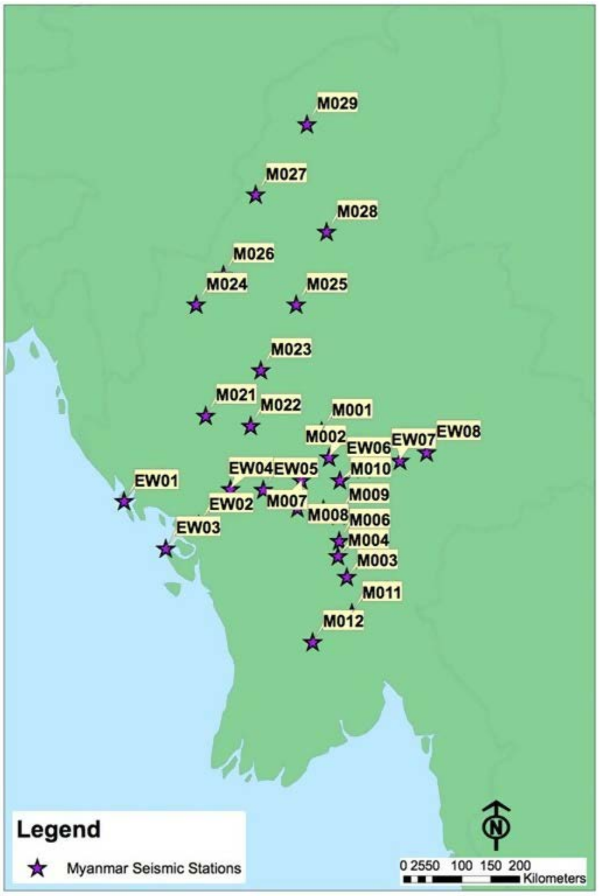
13. (JICA, 2015)
14. (EOS, 2019)

TABLE 4. List of strong motion stations in Myanmar (MNSN, 2019)

STATION CODE	STATION NAME	LATITUDE	LONGITUDE	DATA CENTER
HKA	Haka, Chin, Myanmar	22.6421	93.5995	IRIS DMC
KTA	Katha, Myanmar	24.179362	96.340193	IRIS DMC
KTN	Keng Tun, Shan, Myanmar	21.2857	99.5898	IRIS DMC
MDY	Mandalay, Mandalay, Myanmar	22.0162	96.1123	IRIS DMC
NGU	Ngaung U, Myanmar	21.20572	94.916615	IRIS DMC
SIM	Sittwe, Rakhine, Myanmar	20.1332	92.8852	IRIS DMC
TGI	Taung Gyi, Myanmar	20.768546	97.034076	IRIS DMC
TMU	Tamu, Sagaing, Myanmar	24.2296	94.3003	IRIS DMC

FIGURE 17. Strong motion stations in Myanmar (MNSN, 2019)

FIGURE 18. Strong motion stations (EOS, 2019)



2.3 CYCLONE HAZARD

2.3.1 Overview

Myanmar is significantly exposed to meteorological hazards, such as cyclones and the storm surges they may generate.

Cyclones are generated over warm seas near the equator; seven tropical cyclone basins are identified around the world (see Figure 19); cyclones striking Myanmar are categorized as part of the North Indian Basin (no. 4 on the map), which includes the Bay of Bengal and the Arabian Sea (Hurricane Research Division (NOAA-HRD), 2019). These storms occur in three development stages: “formation and initial development,” “full maturity,” and “decay.” They are classified according to their wind speed as measured on the Saffir-Simpson scale (see Table 5) (UN-Habitat, 2010). As fatal cyclones have struck Yangon, several research projects and studies have been conducted for Yangon and Myanmar; these will be described in this chapter.

FIGURE 19. Seven tropical cyclone basins where storms occur on a regular basis (NOAA-HRD, 2019)

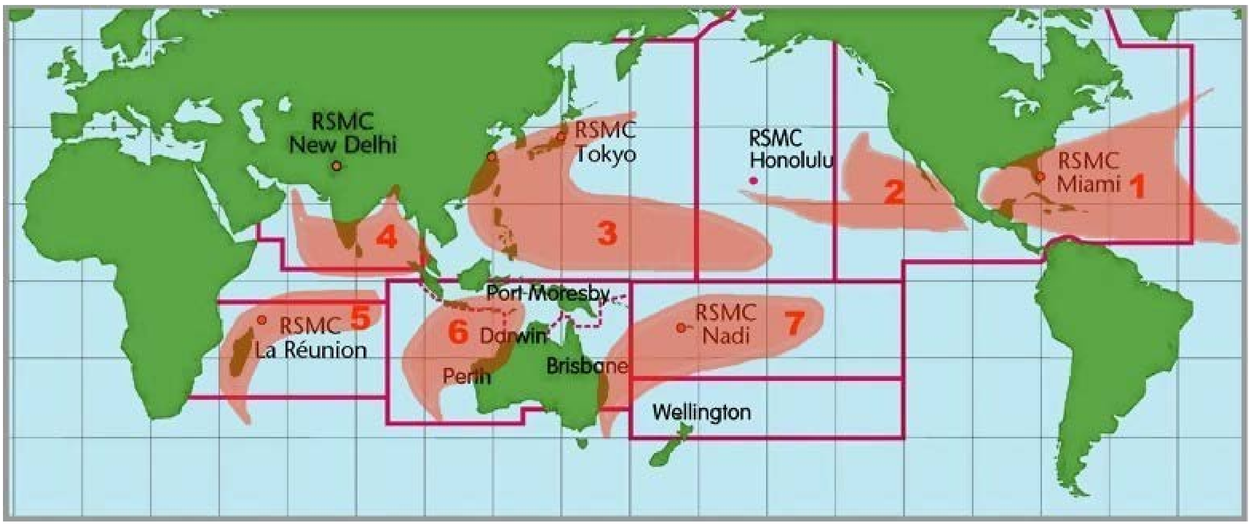
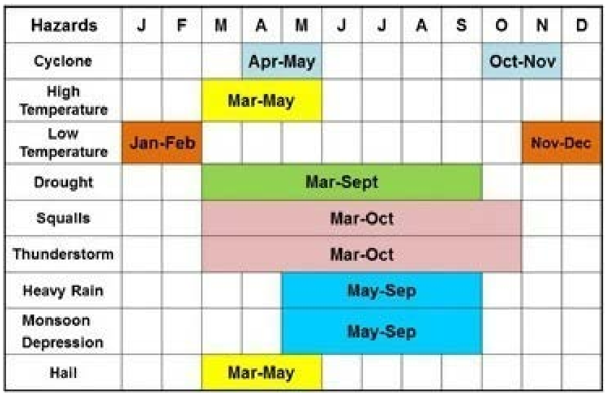


TABLE 5. Saffir-Simpson hurricane/cyclone scale (UN-Habitat, 2010)

SCALE NUMBER (CATEGORY)	SUSTAINED WIND SPEED IN MILES/HOUR (MPH)	DAMAGE LEVEL	STORM SURGE IN FEET (FT)	DATA CENTER
1	74–95	Minimal	4–5	IRIS DMC
2	96–110	Moderate	6–8	IRIS DMC
3	111–130	Extensive	9–12	IRIS DMC
4	131–155	Extreme	13–18	IRIS DMC
5	156 or above	Catastrophic	18 or above	IRIS DMC

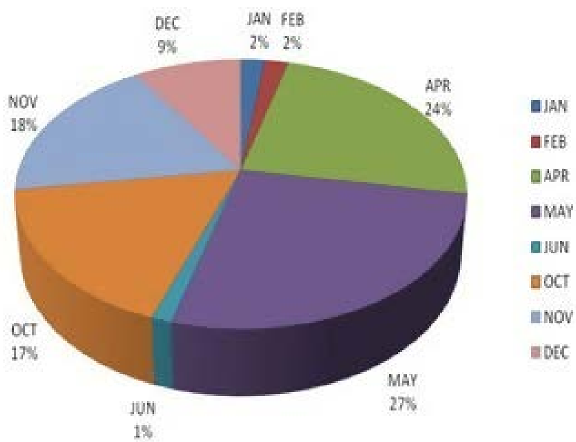
FIGURE 20. Cyclone and tsunami disaster area and seasons in Myanmar (DMH, 2018)

Cyclone and tsunami disaster area



Hazards	J	F	M	A	M	J	J	A	S	O	N	D
Cyclone				Apr-May						Oct-Nov		
High Temperature			Mar-May									
Low Temperature	Jan-Feb										Nov-Dec	
Drought			Mar-Sept									
Squalls			Mar-Oct									
Thunderstorm			Mar-Oct									
Heavy Rain					May-Sep							
Monsoon Depression					May-Sep							
Hail			Mar-May									

Meteorological hazard calendar



Frequency of cyclones (%) which crossed Myanmar coasts (1877–2012)

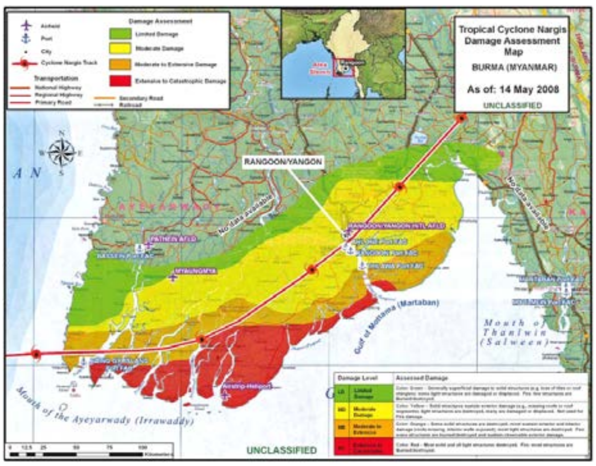
The regions along Myanmar's west coast are threatened by the damage caused by cyclones.

Myanmar is located in the western part of Southeast Asia and has 2,400 km of west coastline facing the Bay of Bengal and the Andaman Sea (highlighted in red in Figure 25). Based on historical records of cyclone activities between 1981 and 2015 (Kyaw, 2017), cyclones occur about six times per year in the area around the Bay of Bengal. As shown in Figure 25, the seasons of cyclones in Myanmar are generally April/May and October/November—the pre-monsoon and post-monsoon periods, respectively (DoM and DFID, 2009; DMH, 2018). The life span of a cyclone is normally less than a week. There are three major concerns associated with cyclones: strong winds, storm surges, and flooding due to heavy rains, as itemized below (UN-Habitat, 2010).

It is also reported that winds can reach 120 mph, storm surges can exceed 10 feet, and rainfall of more than 5 inches can accumulate in 24 hours (DoM and DFID, 2009).

Strong winds and storm surges caused by Cyclone Nargis in Yangon are presented in Figure 26 and Figure 27. The damage assessment map in Figure 26 is overlaid with the track of Cyclone Nargis, highlighting the areas along the track that suffered severe damage. Massive wind forces, as shown in Figure 26, heavily damaged power poles, road signs, buildings, and trees. In Figure 27, the height of storm surges and storm waves are graphed, and flood inundation areas overlaid with the storm's track.

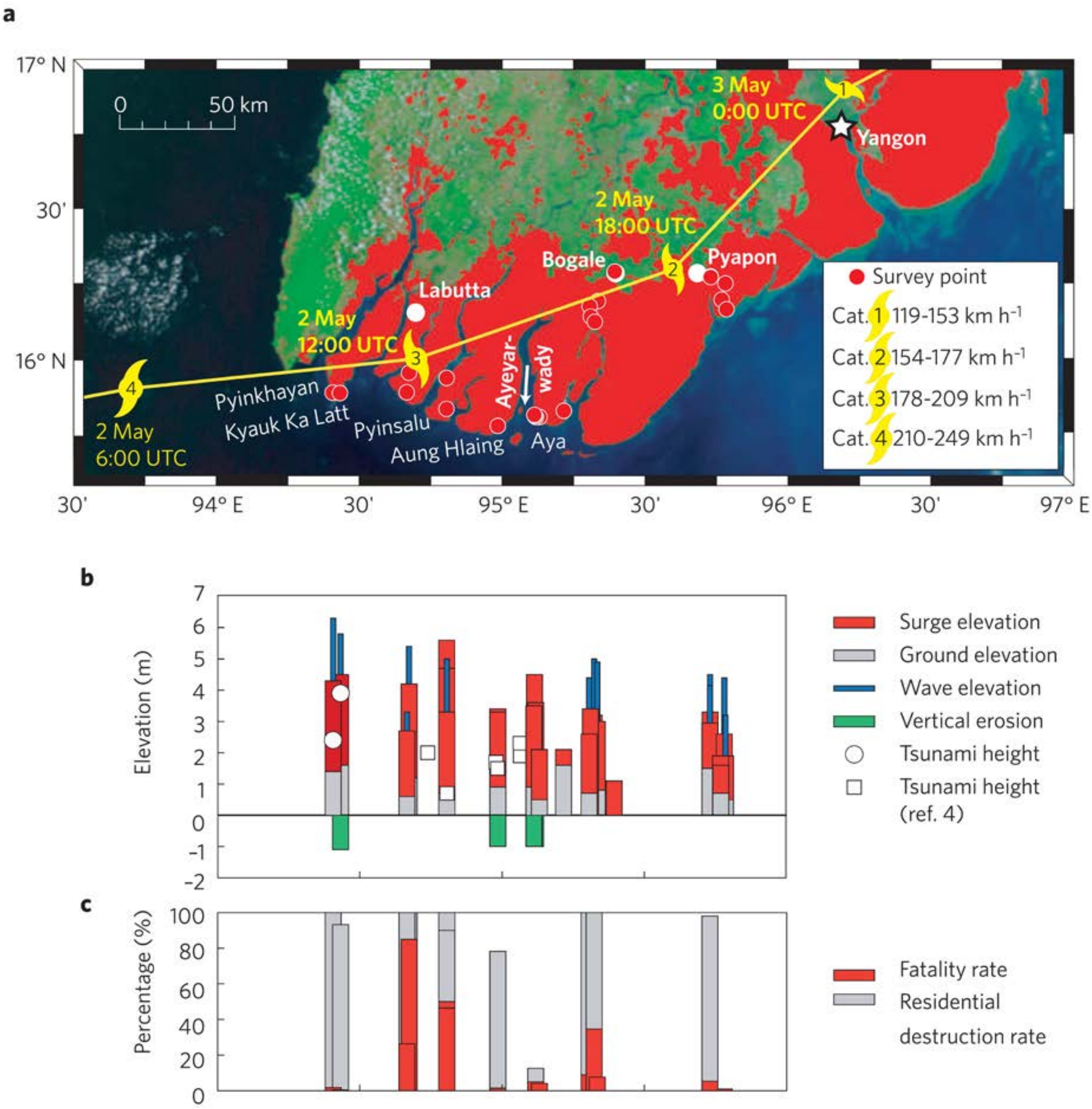
FIGURE 21. **Cyclone Nargis (UNEP, 2009; MES, 2017)**



Damage distribution

Wind gusts

FIGURE 22. Storm surge distribution due to Cyclone Nargis (Fritz et al., 2009)



2.3.2 HISTORIC EVENTS

Many cyclones have affected Myanmar in the past; most of them generated a number of casualties.

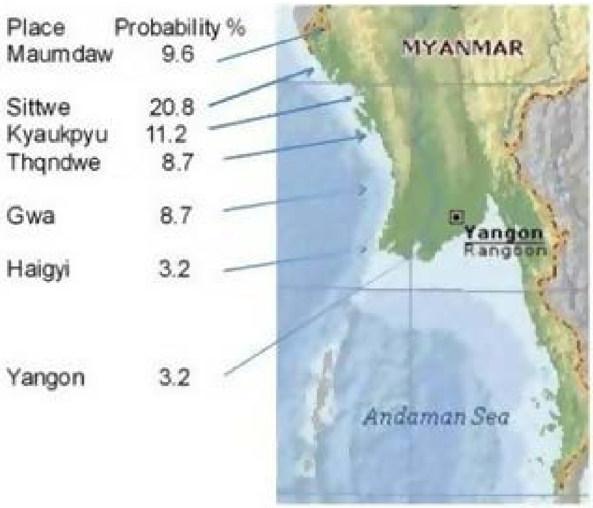
Table 6 enumerates major cyclones in the country between 1947 and 2008. Cyclone landfall statistics and storm surge records of these historical cyclones are shown in Figure 20. In Myanmar, Cyclones come from the west as they are generated in the Bay of Bengal.

As such, a higher statistical probability of cyclone landfall was observed at Sittwe (20.8 percent) and Kyaukpyu (11.2 percent), on the northwestern coast of Myanmar. Even though Yangon is located a little inland from the Andaman Sea, there is still a 3.2 percent probability of landfall in any given year. On the other hand, a storm surge on the southwestern coast of Myanmar is statistically more likely than in the north. Because of these records and the location of the densely populated city, cyclone disasters need to be at the forefront of planning for Yangon.

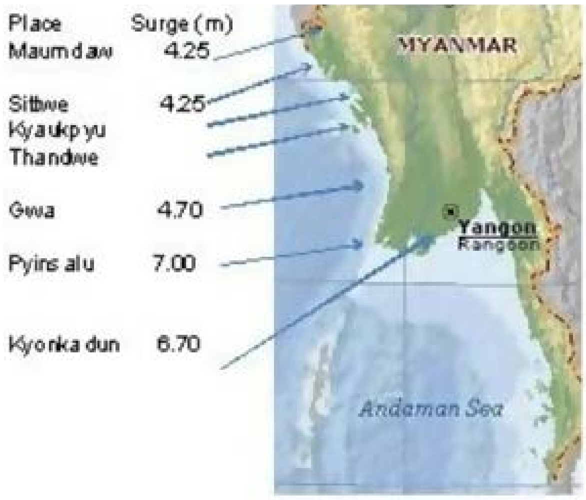
TABLE 6. Major cyclones in Myanmar: 1947-2008 (Departments of Myanmar (DoM) and DFID, 2009)

S/N	DATES OF CYCLONES IN THE BAY OF BENGAL	PLACE OF LANDFALL	LOSS OF HUMAN LIVES AND PROPERTY
1.	October 6–8, 1948	Sittwe	Few dead, 10 million kyat (MMK) in damages.
2.	October 22–24, 1952	Sittwe	Four dead in Yangon, damage in Sittwe and Pathein estimated at MMK10 million.
3.	May 15–18, 1967	Kyaukpyu	Damage in Pathein District estimated at MMK10 million and at MMK20 million in Kyaukpyu District.
4.	October 20–24, 1967	Sittwe	Two dead with 90% of houses destroyed; more than MMK10 million lost in Sittwe; 90% of houses destroyed in Rathey Taung and Kyauktaw; more than 100 people dead; and more than 1,000 heads of cattle lost, with damage estimated at MMK5 million in Monywa District. The water level of the Upper Chindwin River rose 10 ft overnight.
5.	May 7–10, 1968	Sittwe	1,037 dead; 17,537 cattle lost, 57,663 houses destroyed, and damage estimated at MMK10 million.
6.	May 5–7, 1975	Pathein	303 dead, 10,191 cattle lost; 246,700 homes destroyed; estimated loss of MMK446.5 million.
7.	May 12–17, 1978	Kyaukpyu	90% of homes destroyed; damage estimated at MMK200 million.
8.	May 1–4, 1982	Gwa	90% of homes destroyed in Gwa; 27 dead in states and divisions; damage estimated at MMK82.4 million.
9.	May 16–19, 1992	Thandwe (Sandoway)	27 dead in Man-Aung, Rambre, Kyaukpyu, and Thandwe, Taungote; damage estimated at more than MMK150 million.
10.	May 2, 1994	Maundaw	Damage estimated at MMK59 million.
11.	April 25–29, 2006 (Cyclone Mala)	Near Gwa	37 people dead; damage estimated at MMK428.56 million.
12.	April 28–May 3, 2008 (Cyclone Nargis)	Ayeyarwady and Yangon	138,373 people missing or dead; 300,000 cattle killed, 800,000 houses destroyed; over 4,000 schools in more than 6,000 villages destroyed; damage estimated at MMK13 trillion.

FIGURE 23. Statistics and storm surge of historical cyclones in Myanmar (DoM and DFID, 2009)



Cyclone landfall probability along Myanmar coast (1947–2008)



Storm surge observed along Myanmar coast (1947–2008)

FIGURE 24. Track of Cyclone Nargis (JICA, 2015)

FIGURE 25. Residence damage due to Cyclone Nargis in Yangon (MES, 2017)

FIGURE 26. .Track of Cyclone Mora (Naval Oceanography Portal, 2017)

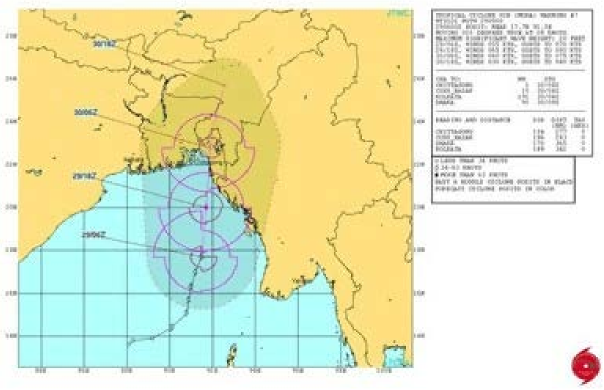


FIGURE 27. Residence damage due to Cyclone Mora in Sittwe (RFA, 2017)

Cyclone Nargis struck in May 2008, mainly affecting the Ayeyarwady and Yangon Regions. It was the worst natural disaster in the history of Myanmar, as documented in several references (Tripartite Core Group, 2008; DoM and DFID, 2009; JICA, 2015). The wind reached speeds of 200 km/hour (h) (125 mph) during Nargis, accompanied by heavy rains. The effects of strong winds were compounded by a storm surge of about 12 ft (3.6 m). As the track of Cyclone Nargis shows in Figure 21, it was generated in the center of the Bay of Bengal and moved eastward, striking Myanmar directly. Cyclone Nargis caused terrible damage, with 138,373 people dead (including those still unaccounted for), affecting 2.4 million people, and causing damage estimated at a total of around MMK4.5 trillion. The number of fatalities in Yangon was recorded at 1,648 people, 1.2 percent of the total. Figure 22 shows a damaged residence in Yangon typical of building damage sustained during the Cyclone.

More recently, in May of 2017, Cyclone Mora, generated in the Bay of Bengal, affected several countries, including Bangladesh, Sri Lanka, Myanmar, Bhutan, and India (see Figure 23). In Myanmar, Rakhine state, Chin state, and Ayeyarwady region were all affected by the cyclone. The damage in Myanmar was reported mostly in Rakhine state, which is located on the west coast.

Wind with speeds of up to 150 km/h (94 mph) were accompanied by heavy rains. Although the number of fatalities in Myanmar was not high, many houses, religious buildings, government offices, schools, and reservoirs were destroyed in Sittwe, the capital of Rakhine state (see Figure 24) (Radio Free Asia (RFA), 2017).

2.3.3 CYCLONE HAZARD PARAMETERS

No cyclone hazard map for Myanmar yet exists. A disaster hazard map is typically estimated in a probabilistic manner by considering the historical records, regional features, and characteristics of the disaster. Not enough research has yet been conducted to develop a cyclone hazard map for Myanmar; although some sources point out that the development of such a map is overdue.

The 95-year return period (Tr) hazard map shown in Figure 28 was the only one found, and it represents both cyclone wind speed (sea area) and earthquake intensity (land area). The cyclone speed zones indicate where there is a 10 percent probability of a storm with high wind speed striking in the next 10 years (i.e., the return period is about 95 years). Five speeds are indicated on the map, from 118–153 km/h (74–95 mph), to 250 or above km/h (156 mph or above).

2.3.4 MONITORING AND ALARM SYSTEM

The Department of Meteorology and Hydrology (DMH) is the focal organization for issuing cyclone warnings and special weather information for the public in Myanmar. The organization (see Figure 29), falls under the Mistry of Transport and Communications, and manages the meteorological observation network, which consists of several types of monitoring stations (see Figure 30). Based on the monitored information and radar and satellite information, DMH analyzes the data and issues a forecast or warning for a cyclone when needed, usually 24–36 hours ahead (see Figure 31). The warning includes cyclone tracks, cyclone wind field, landfall location and time, storm surge warning and advisory. The systematic procedure for cyclone warning dissemination has been developed as shown in Figure 32, and DMH is currently improving its daily and seasonal weather forecasting capacity to further strengthen its early warning performance.

2.4 FLOOD HAZARD

2.4.1 OVERVIEW

Flooding is one of the major natural hazards in Myanmar. Large cities are located along the major rivers – the Ayeyarwady, Yangon, Bago, Sittoung, Thanlwin, and Ataran; the six major river basins in Myanmar are presented in the left-hand map of Figure 33. The city of Yangon is located at the confluence of several river mouths (as shown in the right-hand side of Figure 33), and the flood risk of Yangon is thus especially high. For these reasons, many studies and substantial research regarding flooding in Myanmar, and specifically Yangon, have been conducted, and is examined and described in the following sections.

FIGURE 28. Cyclone (tropical storm) hazard map: Tr = 95 years (OCHA, 2011)

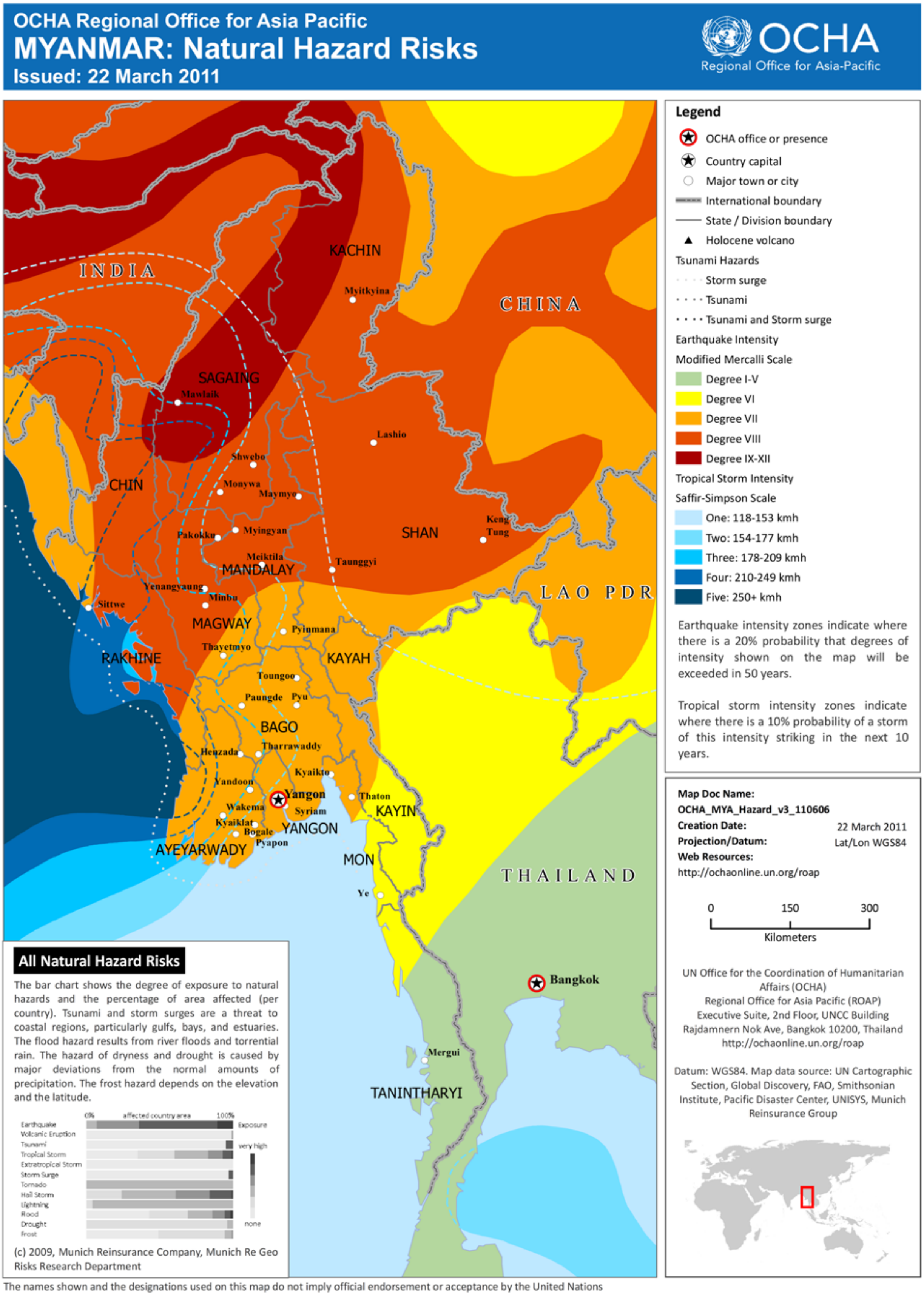


FIGURE 29. Organization chart of meteorology division in Myanmar (DMH, 2018)

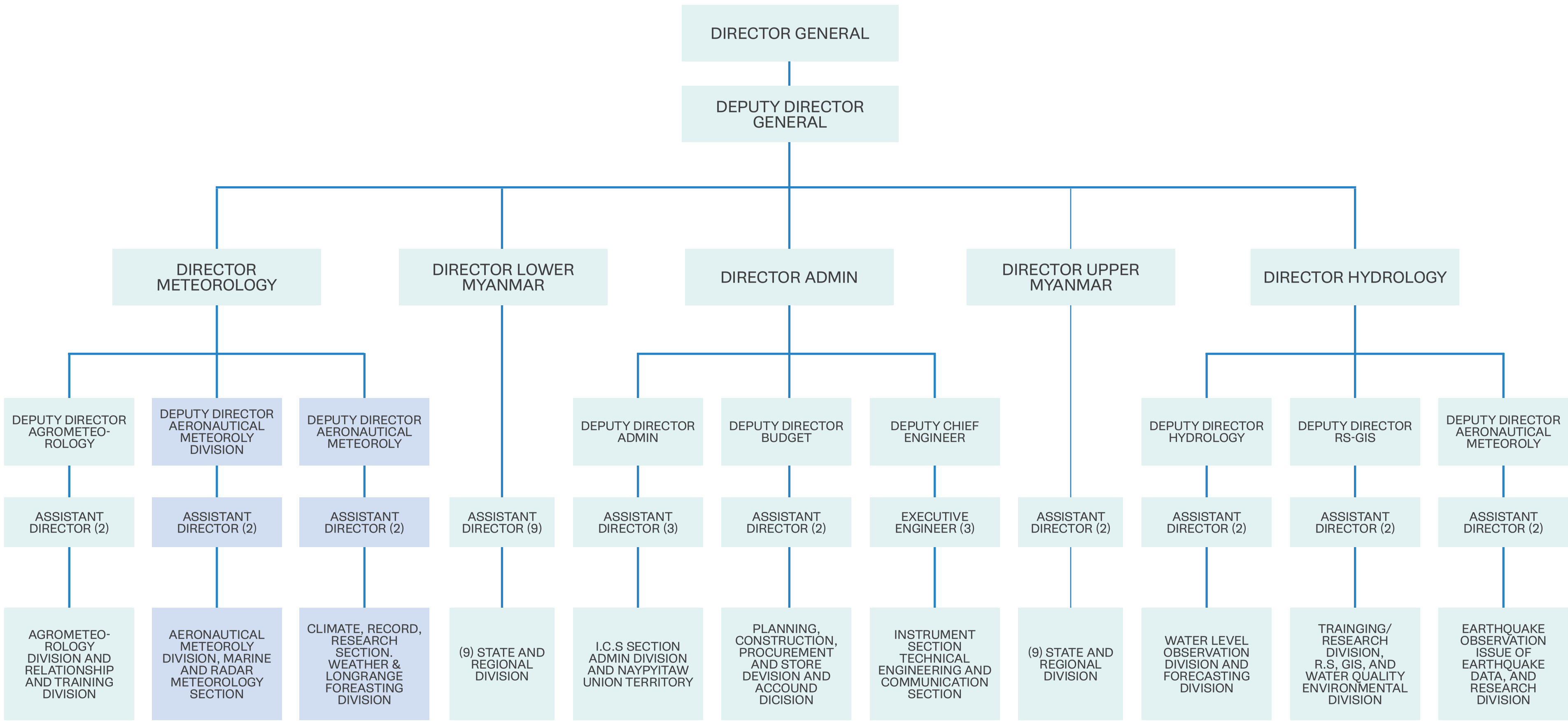


FIGURE 30. Meteorological observation network in Myanmar (DMH, 2018)

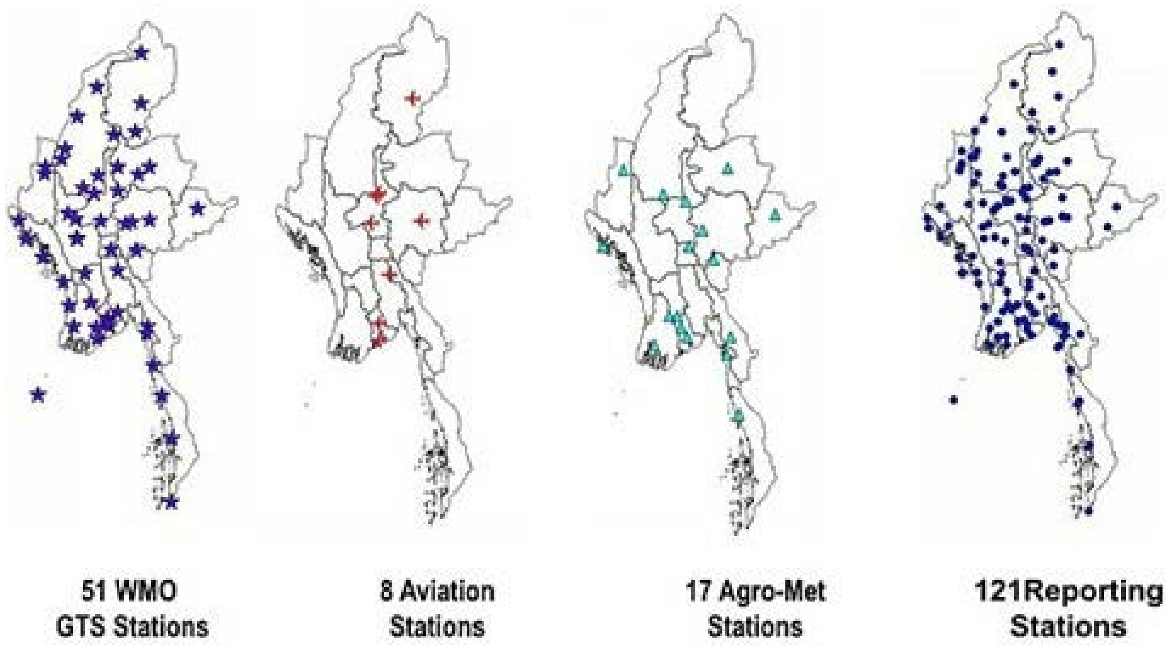


FIGURE 31. Cyclone early warning example in Myanmar (adapted from DMH, 2017)

MOVEMENT AND STORM WIND AREA:	At the time of early morning of 2nd May SCS "Nargis" takes the direction ENE-ward with the speed of 30 mph. Ngayokkaung township and Shwethaungyan township in Pathein district are expected to be under storm wind area in the early morning of 2nd May.
LANDFALL POINT (WHERE, WHEN)	It is expected to landfall coasts along YYYY district and ZZZZ district in the evening of 2nd May.
STORM WIND AREA (HOW)	States and regions shown below will be under storm wind over 50 mph. Ayeyarwady division, Yangon division, West Bago division, South Rakhine state. States and regions shown below will be under storm wind over 30 mph. Mon state, East Bago division, South Mandalay division, South Magway division, North Rakhine state.
SQUALLY WEATHER FOR AFFECTED COAST	Especially, frequent squalls with rough seas will be experienced in Deltaic areas, off and along Rakhine coast, surface wind speed in squalls may reach 100-120mph.
STORM SURGE	The probable maximum storm surge is about 12-14 feet at the towns below in the evening of 2nd May.HainggyiKyun Laputta and MawlamyineKyun And about 10-12 feet in the evening of 2nd May; Ngayokkaung, Shwethaungyan and Ngwesaung townships
GENERAL CAUTION	General caution Due to SCS "Nargis," widespread rain or thundershowers with locally heavy falls, storm wind and flash flood are likely in Laputta, Myaungmya Wakema, Kyaunggon and Nyaungdon townships in Pathein district at Ayeyarwady regions, Yangon, Hmawbi, Twante, Taikkyi and Ngasutaung townships in Yangon region.
ADVISORY	It is advised to take caution against the impact of very severe cyclonic storms such as heavy rain storm wind, storm surge, landslides and flash flood.

FIGURE 32. Cyclone early warning dissemination system in Myanmar (adapted from DMH, 2018)

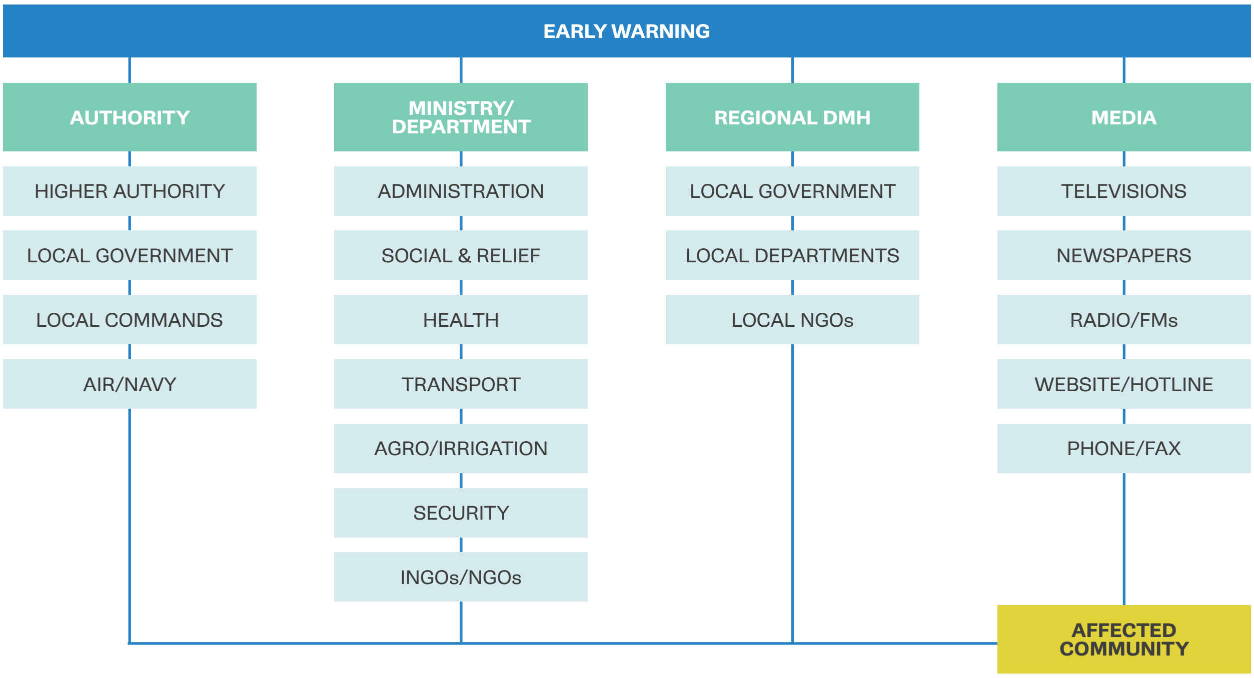
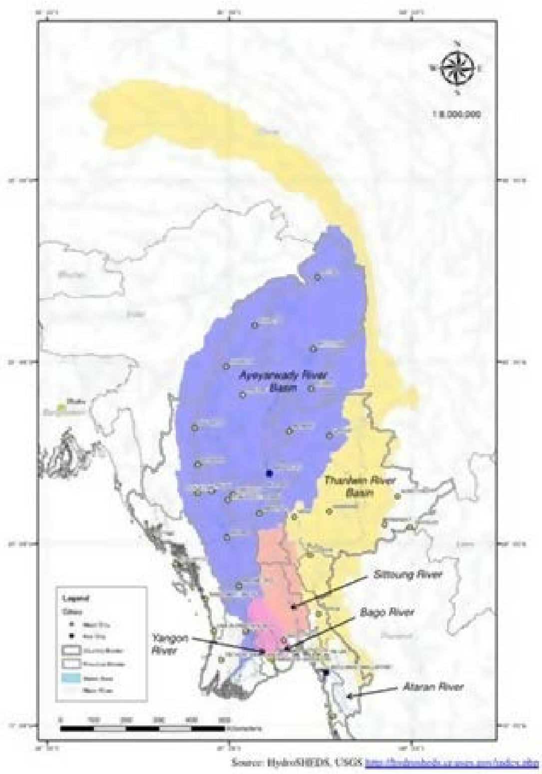
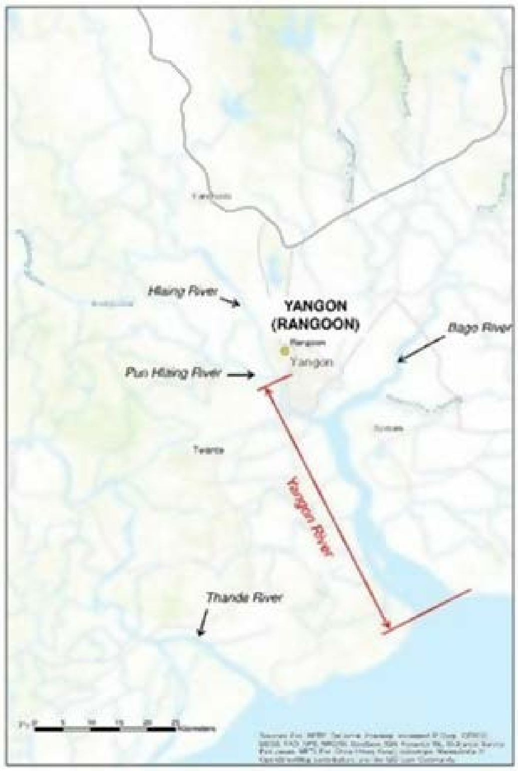


FIGURE 33. Location maps of Myanmar and Yangon (ADB, 2016a)



Myanmar river basin map



Location map of Yangon

TABLE 7. **Major floods in Myanmar (DoM and DFID, 2009)**

NO.	LOCATION	DATE	AFFECTED VILLAGE TRACTS	AFFECTED HOUSEHOLDS	AFFECTED FAMILIES	AFFECTED POPULATION	DEATHS	LOSS (US$)
1.	Homalin, Sagaing Division	8/7/1997	Five in two wards	9,916	9,950	59,594	-	$9,000
2.	Homalin, Sagaing Division	25/9/1997	63	3,867	3,867	28,399	-	$21,636
3.	Paungpyin, Sagaing Division	11/7/1997	5	6,652	6,652	44,143	2	-
4.	No. 2 Myoma Ward, Mawlaik, Sagaing Division	13/7/1997	16	3,622	3,622	21,897	-	-
5.	No. 10 Myopaw Ward, Myikyina Township, Kachin State	9/7/1997	10	4,254	4,471	30,615	4	$3,000
6.	Kayan Township, Yangon Division	7/6/1997	-	1,189	1,189	5,878	-	-
7.	Bago Division	7/7/1997	All in six townships	6,629	6,629	33,768	50	-
8.	Kayin State	1/8/1997	All in five townships	18,804	18,855	109,840	-	-
9.	Hpa-an, Kayin State	13/8/1997	6	2,669	2,669	14,488	-	-
10.	Kyauktaw, Rakhine State	10/7/1997	-	1,030	1,030	5,983	-	$4,545
11.	Wundwin, Mandalay Division	2/6/2001	Thètaw village	463	1,164	2,172	42	-
12.	Monywa, Sagaing Division	18/8/2002	-	9,178	9,460	48,746	-	$213,909
13.	Salingyi Township, Sagaing Division	18/8/2002	-	1,647	1,702	10,216	-	-
14.	Kani Township, Sagaing Division	19/8/2002	-	2,042	2,207	12,048	-	$22,454
15.	Kyaikmaraw Township, Mon Division	19/8/2002	-	829	829	4,686	-	$37,636

NO.	LOCATION	DATE	AFFECTED VILLAGE TRACTS	AFFECTED HOUSEHOLDS	AFFECTED FAMILIES	AFFECTED POPULATION	DEATHS	LOSS (US$)
16.	Hta/16 Ward, Shwepyithar Township, Yangon Division	8/9/2002	-	886	886	4,541	-	-
17.	Hkamti Township, Sagaing Division	3/7/2003	-	1,230	1,536	8,131	-	-
18.	Kyaukse District, Mandalay Division	9/10/2006	All in four wards	1,443	1,763	7,045	-	$31,909
19.	Sagaing Division	11/9/2006	Six near Yaymyetgyi Lake	770	791	5,372	-	-
20.	Kyaukpadaung Township, Mandalay Division	9/10/2006	2	14	18	97	16	-
21.	Bhamo, Shwegu, Myitkyina Townships, Kachin State	24/7/2007	-	600	600	3,167	-	-

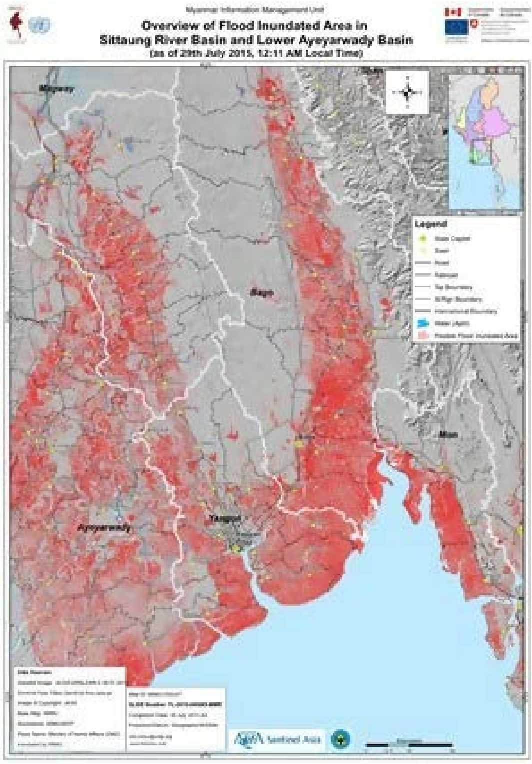
2.4.2 HISTORIC EVENTS

Historically, many floods have occurred in Myanmar.

Table 7 lists major floods between 1997 and 2007. Two major floods occurred in the Yangon Region in 1997 and 2002, in Kayan Township and Shwepyithar Township, and the numbers of affected individuals were 5,878 and 4,541, respectively (DoM and DFID, 2009).

More recently, in 2015, a cascade of natural disasters affected Myanmar (see Figure 34 and Figure 35), including severe floods and landslides induced by heavy rains and by Cyclone Komen. Around 1.6 million people were temporarily displaced, and 132 people lost their lives. The total economic loss was estimated at MMK1.942 trillion; the economic loss of the Yangon Region specifically was about MMK19 million (Government of the Union of Myanmar (GUM), 2015).

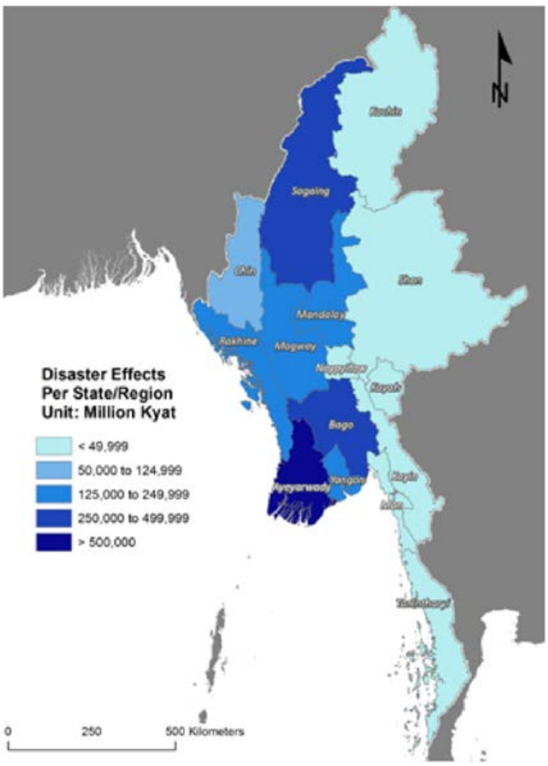
FIGURE 34. **Areas and buildings affected by floods and landslides in Myanmar in 2015.**



Inundated areas around Sittaung River Basin and Lower Ayeyarwady Basin (ADB, 2016a)

Flooded street (GUM, 2015)

FIGURE 35. **Disaster effects caused by floods and landslides in Myanmar in 2015 (GUM, 2015)**



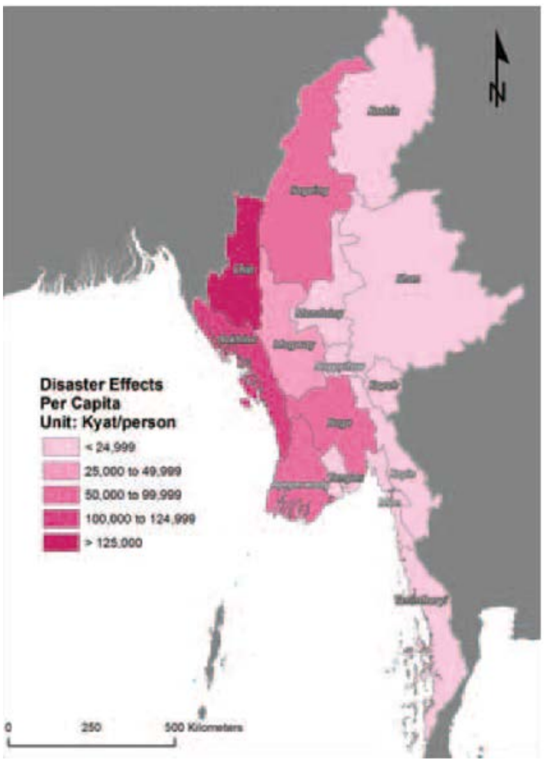
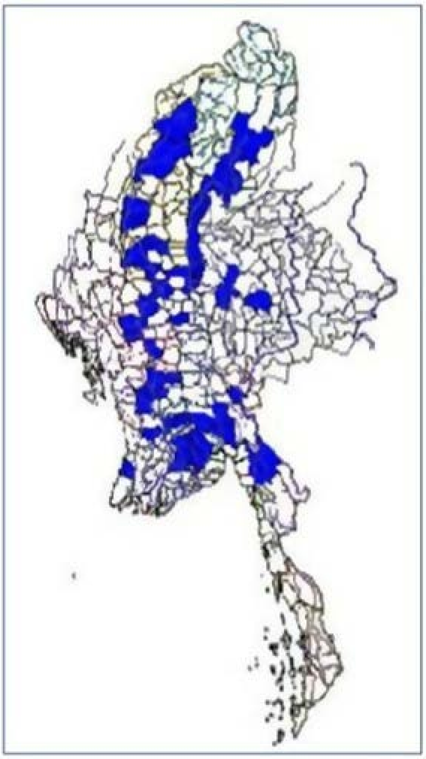
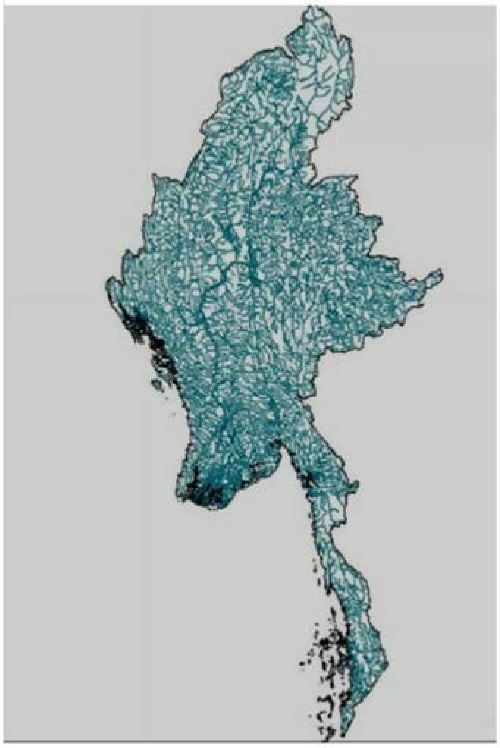


FIGURE 36. **Flood maps of Myanmar (DoM and DFID, 2009)**



Flood-prone areas



Distribution of rivers and streams

2.4.3 NATURAL FLOOD

Flood-prone areas and the distribution of rivers and streams in Myanmar are shown in Figure 36. The months in which flooding occurs most frequently are generally June, August, and late September to October, which in Myanmar is the rainy or monsoon season. Different types of floods occur in different local hydrological situations. A government report (DoM and DFID, 2009) provides a detailed explanation of four types of floods, as itemized on the right:

RIVERINE FLOODS: Flooding at river deltas.

FLASH FLOODS: At the upper reaches of the river systems, normally the mountainous areas. Flash floods are caused by heavy rainfall striking at the headwater region for a period of one to three days.

LOCALIZED FLOODS: In urban areas, due to a combination of factors such as cloudburst, saturated soil, poor infiltration rates, and inadequate or poorly built infrastructure such as blocked drains. In rural areas, these floods are due to the breakage of water resistance structures such as dams, dykes, and levees.

FLOODING DUE TO CYCLONE AND STORM SURGE: Affects coastal areas.

FIGURE 37. **Flood-prone areas in urban Yangon (RHDHV, 2018)**

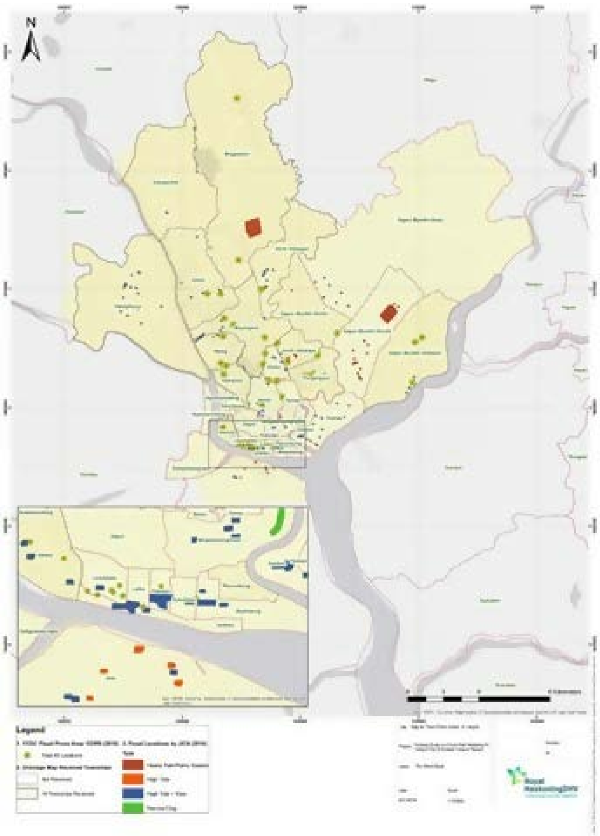


FIGURE 38. **Floods occurred in Yangon (RHDHV, 2018)**

Flood in Pazundaung Township due to a high spring tide in the lower Pazundaung Creek

Localized flood in Myaynigone, San Chaung Township

For Yangon, specific locations have been studied and identified as flood-prone areas (see Figure 37). There are generally two types of floods that occur in Yangon: (i) a combination of riverine floods and flooding due to cyclone and storm surge; and (ii) localized floods. The first type is caused by high water levels in the river and coastal system during the rainy season (see the first picture in Figure 38); the second type is mainly triggered by heavy precipitation (see the second picture of Figure 38). Some flooding can also be attributed to other factors, such as poorly built infrastructure or limited capacity of drainage systems (Royal HaskoningDHV (RHDHV), 2018).

2.4.4 MAN-MADE FLOOD

Flooding caused by insufficient capacity of drainage (urban flood) can occur in the monsoon season in Yangon.

Several sources (DoM and DFID, 2009; Kyaw, 2017; RHDHV, 2018) associated this type of flood with various factors. The city of Yangon's drainage system map is shown in Figure 39. Some examples of the man-made causes of floods during heavy rains are shown in Figure 40; these can include insufficient capacity of the urban drainage system during high tide; reduced drainage performance caused by waste accumulation, informal obstacles, sedimentation and inappropriate maintenance of the drainage network; decreased retention capacity due to urban development; and the encroachment of natural catchment areas due to the expansion of living settlements (DoM and DFID, 2009; RHDHV, 2018).

FIGURE 39. **Primary drainage system of Yangon (RHDHV, 2018)**

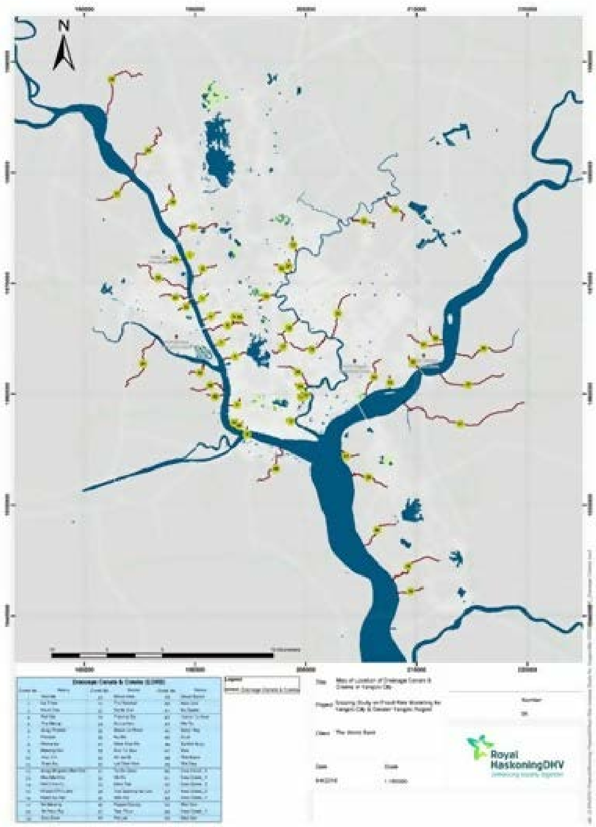


FIGURE 40. **Example of drainage problems in Yangon (RHDHV, 2018)**

Solid waste accumulation obstructing the drainage system

Utility pipes obstructing the flow and increasing the amount of stuck objects

2.4.5 FLOOD HAZARD PARAMETERS FOR YANGON

Flood hazard is typically expressed by the expected inundation depth and spatial distribution of the inundated area.

These features are evaluated based on a target flood intensity, generally defined by the return period of an event. The evaluated results of a flood hazard are projected on a map of the target region called a "flood hazard map" and conceptually explained in Figure 41. A past project established a detailed analysis model for flooding in the Yangon Region (see Figure 42) to create a flood hazard map (ADB, 2016b), consisting of a large basin model and a detailed model. The former is for calculation of the boundary condition of the area to which the latter model is subsequently applied. In this project, the analysis using the large basin model was conducted first, followed by the analysis with the detailed model using the results of the large basin model simulation, such as inflow to the detail model area. The models were calibrated and verified by the inundation records of past flooding in the objective area. Based on the developed analysis models, the project performed a flood hazard assessment and coastal flood assessment. The hazard maps created by the flood hazard assessment based on flooding with a 100-year return period are shown in Figure 43 and Figure 44. The inundation areas are distributed over almost all of the Yangon Region, but the expected inundation depths are just between 0.1 m and 1.0 m. In Figure 45, the coastal flood hazard map based on Cyclone Nargis is shown. The flooded area is very limited in the target region, but the maximum expected inundation depth is 2.0 m. In Figure 46, the flood hazard map based on a combination of a 100-year return period flood and Cyclone Nargis is presented, and the expected inundation areas are widely spread, with depths between 0.1 m and 2.0 m (ADB, 2016a-e).

FIGURE 41. Basic approach of flood hazard map (adapted from ADB, 2016c)

MAGNITUDE OF TARGET FLOOD

- Design flood (e.g., 50-year flood, 100-year flood)
- Largest flood previously recorded

EXTEND OF AREAS TO BE MAPPED

- Identify the target area
- Integrate neighbouring areas and towns that share evacuation shelters

SCALE AND SIZE OF BASE MAP

- Preferable scale: 1/10,000 - 1/15,000
- The base map should be large enough to show evacuation routes and extend of inundation, and preferably individual houses as well.

FIGURE 42. Flood analysis model for Yangon (ADB, 2016b)

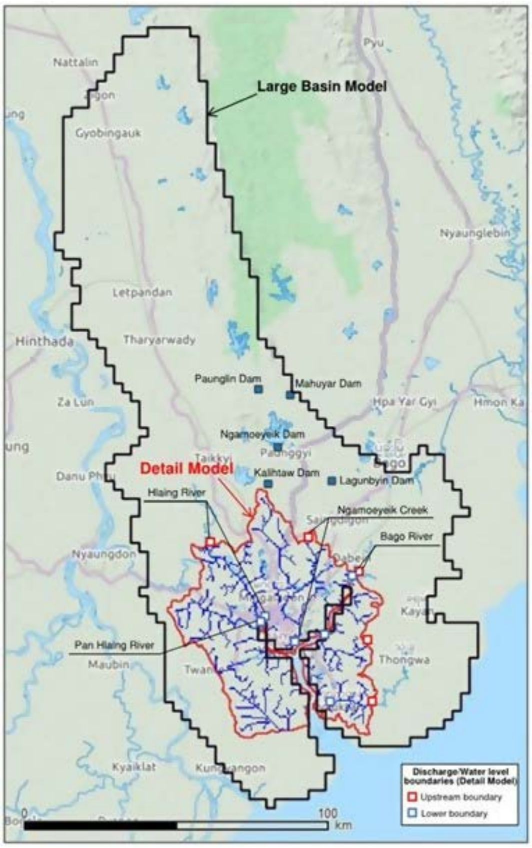


FIGURE 43. Flood hazard map of Yangon: 100-year flood (ADB, 2016d)

FIGURE 44. Flood hazard map of each area of Yangon: 100-year flood (ADB, 2016d)

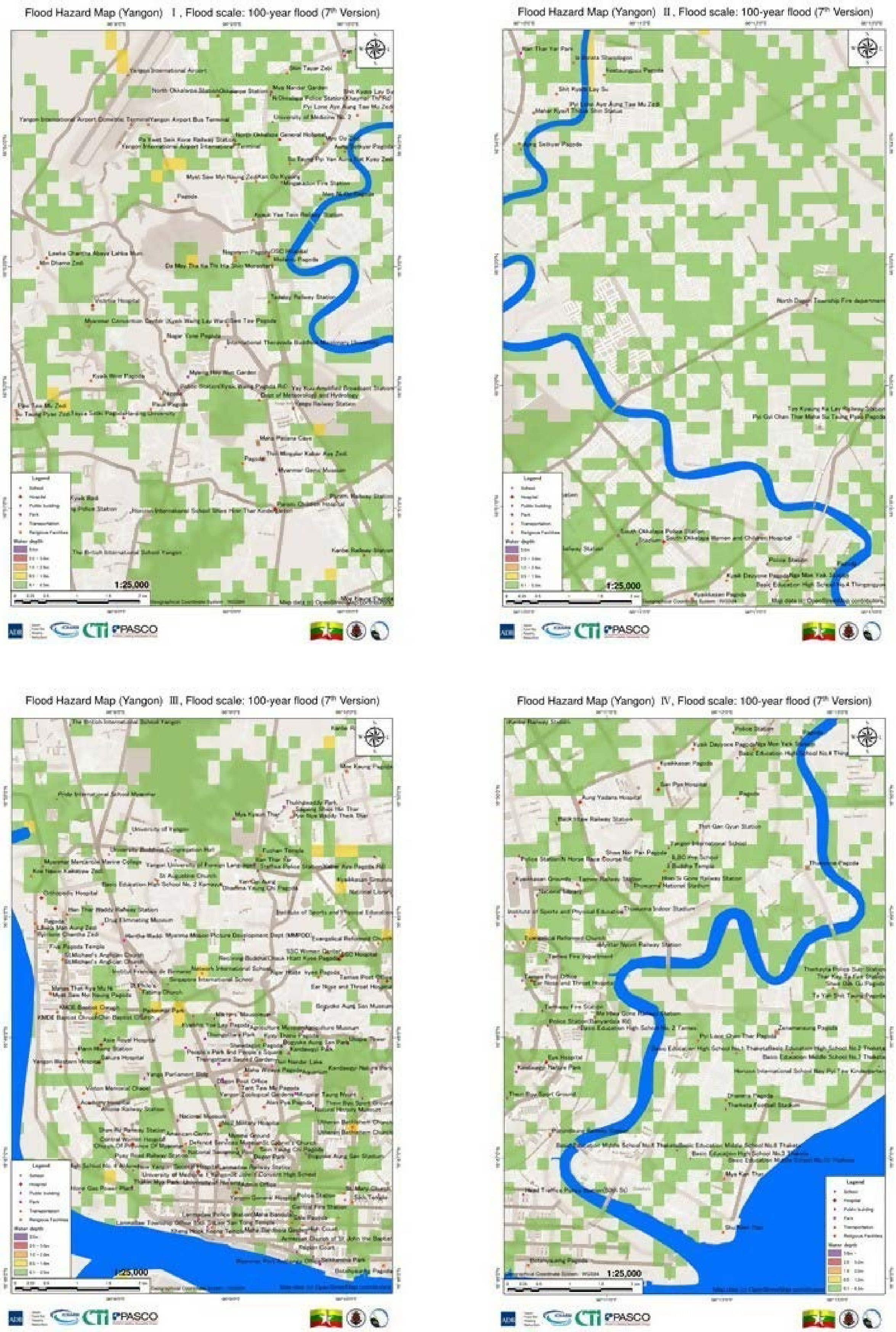


FIGURE 45. Flood hazard map of Yangon: Cyclone Nargis (ADB, 2016e)

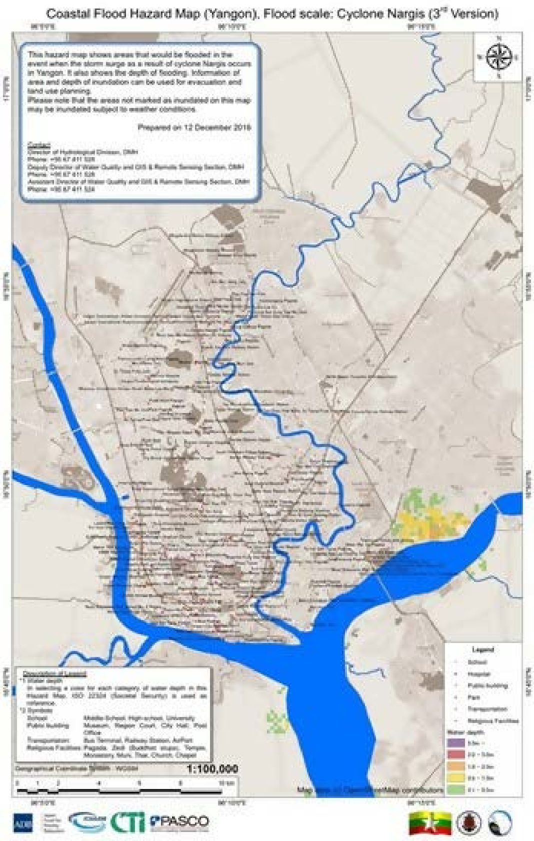


FIGURE 46. Flood hazard map of Yangon: 100-year flood and Cyclone Nargis (ADB, 2016e)

Two separate models were prepared in 2019 as part of Dutch-funded Technical Assistance (TA) in Yangon.

The Yangon Regional Hydraulic Model, prepared by Arcadis in 2019, describes the hydraulic system of the Greater Yangon Region in one and two dimensions. The model can provide a general insight in the flood events in the modelled area. The model is built from three separate modules that can each be run in isolation: (i) the 'channel flow model' with a domain covering the main river channels within the project area. This domain is meant for channel-flow and does not allow for overland flow. This model can be used for discharge simulations without overbank inundation; (ii) the 'overland flow module' with a domain covering the main channels and the 'dry' areas in between, at least for the Yangon area. This model allows for simulation of both overland flow and channel flow as well as pluvial inundation and coastal flooding; and (iii) a 'salinity model', which is a three-dimensional version of the channel flow model specifically dealing with the simulation of salinity intrusion. It is intended for broader river basin management studies and is not relevant to the flood hazard study.

The Yangon Regional Hydraulic Model simulates the physics and the general hydrodynamic behavior in the Greater Yangon Region with reasonable accuracy. The model can be used to analyze the impact of system interventions (impact assessment tool) and as such it can be used as decision-support tool. The model can also be used to analyze the relative impact of climate change. However, the model cannot be used for design and engineering purposes for which more accurate and reliable information is generally required (Arcadis, 2019).

The Yangon Flood Model (YFM), prepared by Royal HaskoningDHV (RHDHV) in 2019, focuses on Yangon City and is expected to have a total model extent of about 280 km2. This hydraulic model describes the urban hydraulic system of Yangon City in high resolution in (one and) two dimensions. The model facilitates analysis of the urban drainage system under various climatological and hydraulic conditions based on now and in the future. Unlike the Regional Hydraulic Model, the YFM is intended to serve as a design tool to simulate different flooding scenarios, and has a much higher level of detail compared to the Regional Flood Hazard Model.

In this way it is much better able to simulate the (flood) water flows in the urban drainage system as a result of rainfall. The YFM study comprised two main parts. First, the Flood Hazard Model simulates the flow of stormwater as a result of rainfall including any flooding that may occur in case the drainage network is not able to facilitate appropriate stormwater discharge. The model is able to (i) simulate water movement caused by rainfall, fluvial and coastal sources; (ii) function as a planning tool to identify bottle necks; (iii) assess the impacts of possible drainage measures; (iv) evaluate the effectiveness and sustainability of these measures; and (v) produce flood maps that are compatible as input for further flood risk assessments. The Flood Hazard model is linked to a regional hydraulic model, which conceptually describes the rainfall runoff processes of Yangon's external river system and provides general insight in the volume of rainfall that needs to be drained to neighboring rivers and canals. Second, the Urban Flood Risk Model generates a flood risk profile and spatial flood risk maps of the urban area by combining the flood depths at a certain probability (output of the Urban Flood Hazard Model) with the expected impact in terms of direct economic damage and loss of life (RHDHV, 2019).

SWECO also prepared a hydraulic model under Component 2 of the World Bank SEA DRM project. The model has been calibrated against experienced flooding in Yangon and used for testing the proposed design for upgrading the drainage system in 6 townships within Yangon's Central Business District (CBD). The results show a significant improvement in flood risk areas, and the design shows no flooding with simulations for a 1 in 10-year rainfall return period.

2.4.6 MONITORING AND ALARM SYSTEM

The hydrological division of the Department of Meteorology and Hydrology is in charge of forecasting and warning against floods in Myanmar.

This is summarized in Figure 47. The organization manages hydrological forecast stations and telemetry water level monitoring system stations (see Figure 48). Based on the monitored information at the stations, DMH periodically issues water level forecasts for the twelve major rivers, and disseminates flood warnings and flood bulletins during the monsoon season, as exemplified in Figure 49. The flood early warning system in Myanmar also utilizes this equipment and the stations, and the systematic procedure of flood warning dissemination has been developed as shown in Figure 50. However, DMH states that a flash flood forecast/warning system still needs to be established in Myanmar to further reduce damage from flooding (DMH, 2018).

FIGURE 47. Organization chart of hydrological division in Myanmar (DMH, 2018)

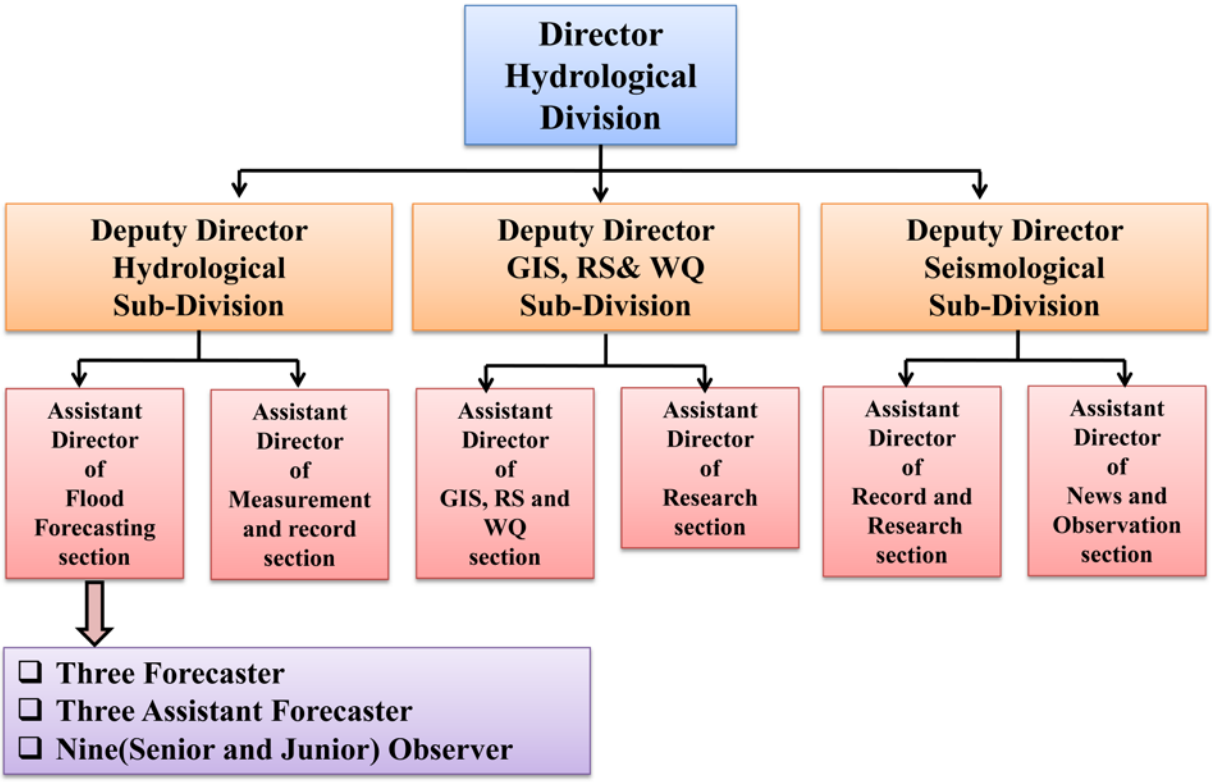
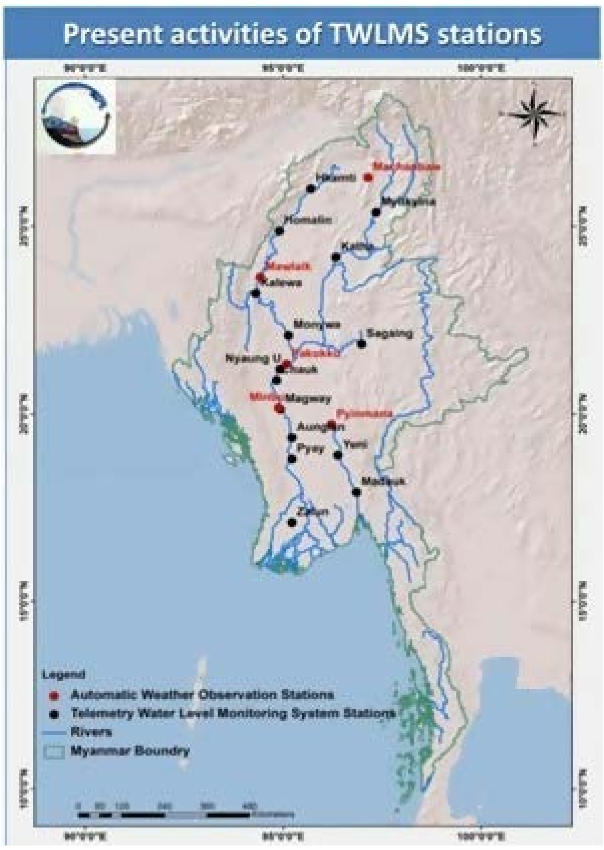
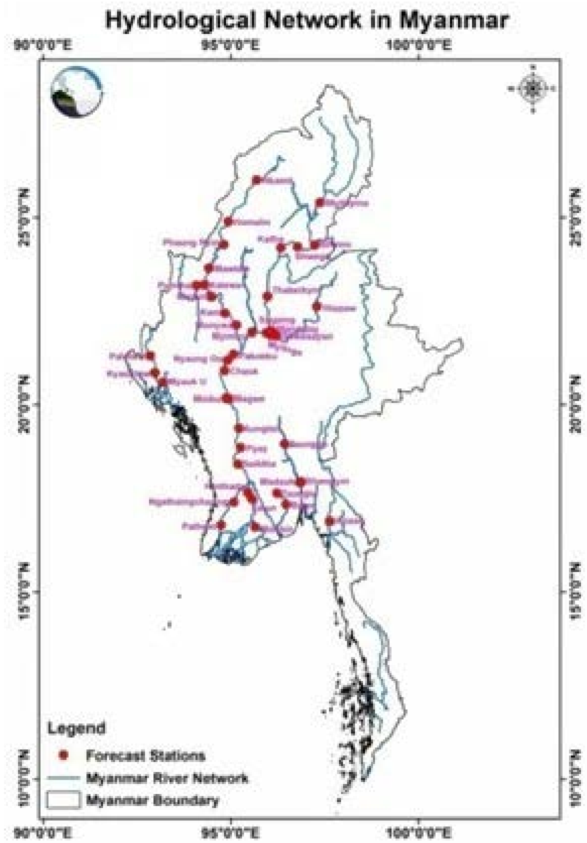


FIGURE 48. Flood monitoring network system in Myanmar (DMH, 2018)



Telemetry water level monitoring system stations in Myanmar



Hydrological observation stations in Myanmar

FIGURE 49. Flood early warning examples in Myanmar (DMH, 2018)

FLOOD WARNING

(Issued at 16:00 hr M.S.T on 9-8-2017)

According to the (15:30) hr M.S.T observation today, the water level of Chindwin River at Hkamti is observed as about (6)feet below its danger level. It may reach its danger level during the next (2) days.

It is especially advised to the people who settle near the river bank and low lying areas in Hkamti Township, to take precaution measure.

FLOOD BULLETIN

(Issued at 14:00 hr M.S.T on 12-8-2017)

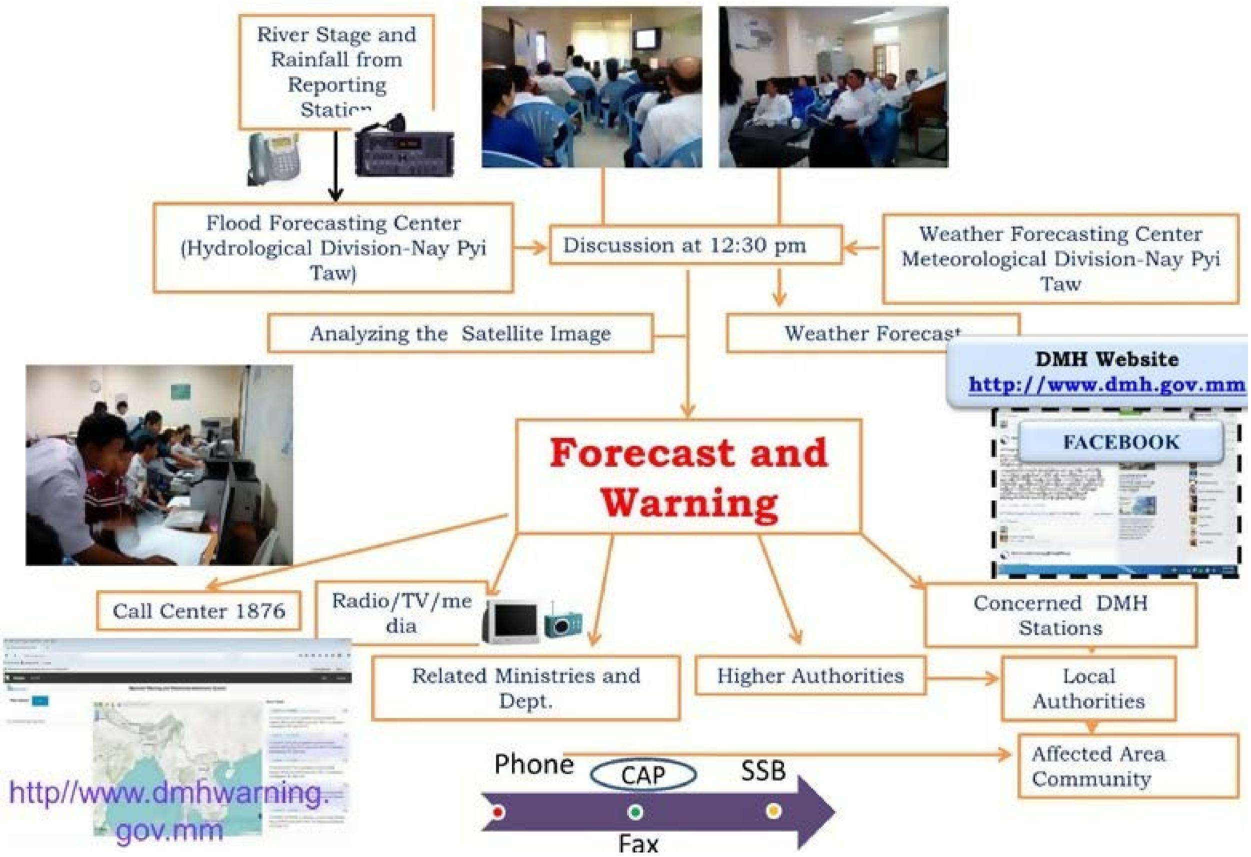
Flood condition of Chindwin River

According to the (13:30) hr M.S.T observation today, the water level of Chindwin River at Hkamti has exceeded about (1 1/2) feet today above its danger level, it may continue to rise about (1) foot during the next (1) day and may remain above its danger level.

Advisory

It is especially adviced to the people who settle near the river bank and low lying areas in Hkamti Township, to take precaution measure.

FIGURE 50. Early warning information and dissemination system in Myanmar (DMH, 2018)



2.5 FIRE HAZARD[15]

2.5.1 OVERVIEW

Fire accounts for 70 percent of disasters in Myanmar, and annual losses are estimated in US$ million (UN-Habitat, 2011).

As the country urbanizes, the population of Yangon has grown at a fast pace, leading to more congested dwellings and an increase in vulnerable informal settlements. Between 2011 and 2018, more than 2,060 fires occurred in the city of Yangon. There are many overcrowded residential buildings and factories in the city, which contributes to the large number of residential and industrial fires, as opposed to wild fires.

There are several other causes for the prevalence of fire in the city, including:

CONSTRUCTION PRACTICES: A large number of houses are constructed using bamboo and wood framing, wood-planked and thatched floors, and corrugated metal roofs. This type of construction increases vulnerability to fires.

ELECTRICAL-RELATED CAUSES: These include the improper use of appliances and faulty connections.

COOKING-RELATED CAUSES: These include grease fires, negligent use of kitchen fire, use of oil indoors for cooking, and uncovered cinders left after cooking.

HEATING APPLIANCES.

FACTORY FIRES: These could be the result of explosions or transportation or improper stocking of flammable material.

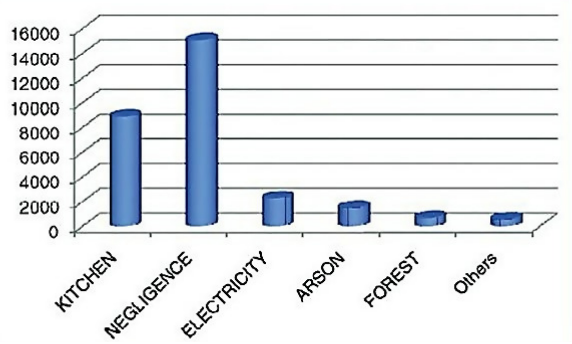
ARSON.

OTHER.

According to the Fire Services Department (FSD, 2009), between 1983 and 2009, negligence and kitchen fires were the most common cause of fire outbreak (see Figure 51).

In Yangon, for the past ten years, negligence and electrical issues were identified as the causes for 977 and 762 out of 2,062 fires, respectively (FSD, 2019). In 2017, fires in Yangon resulted in 49 fatalities, 197 injuries, 1,304 damaged houses, and 1,649 displaced people (FSD, 2019).

FIGURE 51. Causes of fire in Myanmar, 1983–2009 (FSD, 2009)



2.5.2 HISTORIC AND RECENT EVENTS

The Yangon Region is classified as one of the most vulnerable to fire hazard in Myanmar.

From 2000 to 2007, approximately 35 percent of all fire cases in the country, and 14 percent of the costs associated with fires, occurred in Yangon (see Table 8) (ADPC et al., 2009). Kitchen-related incidents and negligence contributed to 78 percent of fires in the 2000–2007 period. These fires resulted in 298 fatalities and 607 injuries, and affected over 135,000 people.

Some of the major fires in Yangon include: [16]

- A 2005 fire in the Hlaing Township (West District) affected 9,145 people and resulted in US$56,000 in damage (ADPC et al, 2019).
- A 2017 fire destroyed the iconic Kandawgyi Palace Hotel, resulting in at least one fatality. This was a colonial-era building, its oldest part dating back to the 1930s. The fire started because of old wiring in decorative lighting, and resulted in damages of over US$27 million, according to the East District Police. Hundreds of firefighters attempted to control the fire but were not successful (see Figure 52) (CM, 2017).

15. In this report, fire implies urban fire, in contrast to forest or wild fire, which is not part of the study.

16. Probably the most infamous fire in city is the 2018 fire at the landfill site. The fire burned for weeks, sent a number of people to hospital, and choked the city. However, since it did not affect the built environment, this fire is not discussed in the report.

TABLE 8. Fire cases in Myanmar and Yangon in 2000-2007 (ADPC et al., 2009)

DIVISION/REGION	FIRE CASES		ECONOMIC LOSS	
	NO.	%	AMOUNT (US$ MILLIONS)	%
Yangon	2,431	35%	1.1	14%
Mandalay	1,214	18%	0.48	6%
Sagaing	800	12%	0.22	3%
Others	2,470	36%	6.1	77%
Myanmar	6,915	100%	7.9	100%

- A 2018 factory fire resulted in US$53,000 worth of damage. The fire destroyed a steel-structure building and a large number of plastic pellets. The event was attributed to a driver switching on an electric pot to boil water and leaving it on. Once the main switches were turned on, the fire spread quickly and required 47 fire engines to extinguish it (Xinhuanet, 2018a).
- A massive 2018 fire at the electronic factory in Hlaingthaya Township (North District) burned the factory down (see Figure 53) (Xinhuanet, 2018b).

2.5.3 FIRE HAZARD MAP

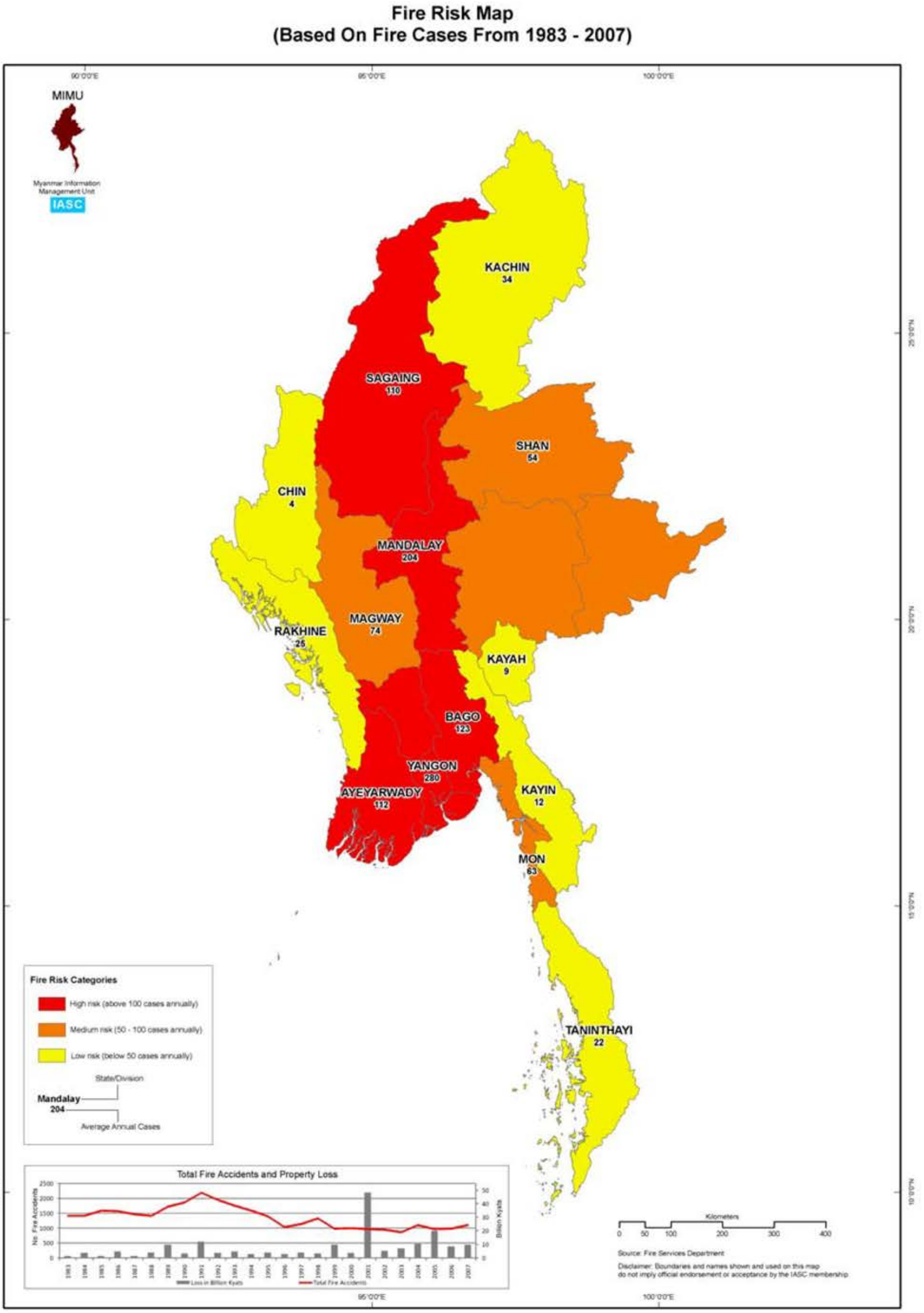
The fire hazard map for the country is based on data from the years 1983-2007 and is presented in Figure 54 (ADPC, 2009).

Note that the Yangon Region, with 280 annual cases (a significantly higher number compared to the other regions), is ranked the highest.

FIGURE 52. Kandawgyi Palace Hotel fire (CM, 2017)

FIGURE 53. Electric factory fire (Xinhuanet, 2018b)

FIGURE 54. **Fire risk map (ADPC et al., 2009)**



2.5.4 FIRE IN THE AFTERMATH OF AN EARTHQUAKE

2.5.4.1 Overview

Fire in the aftermath of an earthquake is a serious secondary hazard.

After an earthquake, broken gas lines or fallen electric lines can lead to fire. At the same time, the water supply needed to fight the fire could itself be out of operation because of broken water mains.

Based on the reports from fire departments, the primary causes of fire after the 1989 Loma Prieta earthquake included gas leaks, electrical wiring problems, overturned water heaters, and overturned hot plates (Alysian, 1992).

A single broken gas distribution pipe led to a fire that leveled an entire city block (Figure 55) (NISEE, 2019). As a result of the earthquake, by far the largest number of fires occurred at sites with weak soil (unconsolidated or fill); the seismic waves, amplified for these types of soil, had resulted in increased forces on utilities infrastructure, including gas pipes and electrical lines.

Table 9 presents the statistics for the fires in the aftermath of earthquakes for selected earthquakes in the USA (Alysian, 1992). Note that fires have occurred in the aftermath of even moderate earthquakes. In the aftermath of the 1994 Kobe earthquake in Japan, nearly 150 separate fires destroyed thousands of buildings (Figure 55 and Figure 56) (EQE, 1995).

TABLE 9. Earthquake-induced fires for selected US earthquakes (Alysian, 1992)

EARTHQUAKE	YEAR	MW	FIRES
San Francisco	1906	8.3	58
Long Beach (CA)	1933	6.3	13
Alaska	1964	8.4	7
San Fernando (CA)	1971	6.6	109
Morgan Hill (CA)	1984	6.2	6
Whittier (CA)	1987	5.9	6
Loma Prieta (CA)	1989	6.9	67

FIGURE 55. Fire in the aftermath of the 1989 Loma Prieta earthquake (NISEE, 2019)

FIGURE 56. Fire in the aftermath of the 1995 Kobe earthquake (EQE, 1995)

2.5.4.2 Considerations for Yangon

Yangon is considered a region of moderately high seismicity.

As such, the city and region experience earthquakes that can result in moderate damage and it is important to ensure that structures are protected from further damage resulting from fire. Lessening the probability of fires would also allow for a more rapid recovery. The fires after Loma Prieta and Kobe earthquakes discussed in the previous section are directly attributed to failures in the electrical or gas lines. These events provide insights and recommendations for measures that can be implemented in Yangon to reduce the risk of fire, including the following:

- Implement a program of rapid assessment of essential facilities, including fire stations, after earthquakes
- Provide bracing for pipes that carry hazardous or inflammable material
- Provide flexible connections for underground natural gas lines
- Provide earthquake-resistant design for all fire protection systems
- Provide flexible connections for sprinkler systems to ensure they remain operational after earthquakes
- Use enhanced earthquake-resistant design for fire and communication centers

2.5.5 IMPACT OF YANGON BUILDING CONSTRUCTION AND USE

Construction type is a major factor in Yangon's fire hazard.

While bamboo or timber (BT) framing and wood-planked floors and roofs contribute to the fire hazard, there are other contributing factors to consider:

- As the city population grows, housing has become more congested. This, in turn, has led residents to use areas designated as fire exits for storage, which can lead to accidental fires in addition to hindering those trying to escape from fire.
- Very few small informal settlements remain in the downtown area. However, outside the inner city, a large percentage of the city residents live in some kind of informal settlement. These areas are highly susceptible to fire. Furthermore, fighting fires in such areas is complicated, as roads are often not passable for fire trucks. Thus, overcrowding in informal housing could hamper the effort to contain the fire.
- Newer, taller buildings have specific requirements for fire control, such as the type, number, and spacing of sprinkler systems. There has only been one fire in a high-rise building, and it occurred during construction (FSD, 2019).
- Although there are requirements for buildings to be checked for fire prevention measures, an improvement in quality control can further reduce fire hazard.
- There are a large number of factories in Yangon, many of which store or process inflammable material.

2.6 DISCUSSION

2.6.1 EARTHQUAKE HAZARD

In recent years, considerable effort has been undertaken by a number of organizations, to characterize the seismic hazard in Yangon and beyond. These organizations include MES, MEC, the Yangon Technological University (YTU), and others; a review of their findings by researchers shows consistent results. In particular, the following is noted:

- The city has experienced historic and relatively recent earthquakes that have resulted in fatalities, injuries, and significant structural damage.
- The city is susceptible to earthquakes of M7.0 or larger that can occur on the Sagaing or other faults.
- For most of the city, the underlying soil can be classified as site D. However, there are pockets of class E, and areas near the river that have soft soil due to landfills. The presence of soft soil is consistent with the comments from stakeholders who stated that piling and, at times, deep piling, is required in certain areas of the city and for taller buildings to ensure bearing on competent soil is reached.

- For moderate to large earthquakes, liquefaction hazard must be considered in areas identified as susceptible.
- Probabilistic seismic hazard maps have been developed for both DE (475-year) and MCE (2475-year) events. DE is the level of seismicity implied in modern building codes (such as ASCE 7 and MNBC 2016). Structures designed per code are expected to provide life preservation (with fatality rates of 0.2 percent or less) for such events. MCE is not directly considered in codes, but the buildings designed per modern code are expected to have a low probability of collapse (less than 10 percent) for events of such magnitude. PGA designates the level of shaking that can be anticipated at the site. Sa (0.2-sec) denotes the level of forces that would be experienced by shorter (one- to five-story) buildings; taller buildings are more flexible, and their response correlates more closely to S1.
- Taking site amplification into account, for DE, Ss and S1 are approximately 0.6–0.8 g, and 0.4–0.6 g, respectively. To preserve life, the buildings must either be strong enough to withstand this level of shaking (not simple to achieve), or ductile enough to dissipate the seismic energy and reduce the level of force. Similarly, for MCE, Sa and S1 are approximately 1.2 g and 0.7 g in downtown townships. For buildings to survive this type of demand, adequate ductile detailing must be provided.
- The 2017 M5.1 earthquake resulted in fatalities and the collapse of a building wall. It is noted that the 2017 earthquake is several orders of magnitude smaller than an earthquake magnitude that can be expected to impact the city; an increase of one order of magnitude corresponds to approximately 30 times the seismic energy of the preceding magnitude. Thus, an earthquake of M7.0 or more can have severe consequences. As a contrast, in California or Japan, earthquakes of M5.0 (or even 6.0) are felt but usually do not result in any structural damage or fatalities.
- In the past few years, a digital strong motion recording program has been implemented, and the stations have come online. This is an important development, as data from these stations can be used to further understand the seismicity of the city and country, help to correlate observations in the aftermath of future earthquakes to strong motion data, and assist in preparing future editions of the MNBC.

Digital data corresponding to site class and seismic hazard parameters for the city was not available for this study. If such data is available, it is recommended that an online platform be developed to store it. Engineers could then access the portal and, by typing the coordinate systems for a building site under design, obtain the site class and spectral acceleration parameters. The data can then be used in seismic design. In addition, it is recommended that the strong motion data be catalogued online for use by researchers. Such information could provide valuable insights to improve design practice in the future and can assist in preparing site-specific acceleration histories for the city of Yangon that can be used in future design of critical or high-performance buildings where a nonlinear response history analysis would be used.

At the time of writing, a comprehensive five-year research program was underway as a collaborative effort between YTU and the University of Tokyo (Science and Technology Research Partnership for Sustainable Development (SATREPS), 2016). One of the project components examined site conditions in Yangon, and both VS, 30 maps and site amplification maps have been developed. However, these maps were not available for inclusion in this report.

2.6.2 CYCLONE AND WIND HAZARD

Significant research has been conducted for cyclone hazard in Myanmar by local and international organizations.

Cyclone track and intensity forecasts are generally feasible, based on appropriate monitoring systems and accumulated statistical records. Myanmar has a cyclone forecast and early warning system in place, and it is vital to continue improving the system technology and database processes. Developing comprehensive cyclone hazard maps is also crucial for disaster risk reduction.

- Yangon is not the most threatened area in Myanmar compared to more cyclone-prone areas along the west coast. However, severe cyclones have hit Yangon in the past and caused significant damage.
- The cyclones striking Yangon are generated in the Bay of Bengal and cause a marked increase in wind speed and storm surge height. The main concerns associated with cyclones in the city are related to strong winds, storm surges, and floods due to heavy rains.

- The cyclone hazard maps created for Yangon and Myanmar are not yet comprehensive and need to be developed further for disaster preparation and loss reduction.

A cyclone early warning system has been established and is effectively operated in Myanmar; however, continuous improvement of existing systems and processes is fundamental.

2.6.3 FLOOD HAZARD

Substantial efforts have been undertaken by several local and international organizations in relation to flood hazard.

The origins of flooding (i.e., climate, precipitation, water bodies, cyclones, seasons and drainage systems) are intricately intertwined in Myanmar, and it is therefore important to conduct research exploring multiple aspects. Identifying the expected time of year and intensity of flood hazards in each region (hazard map) is essential not only for loss reduction but also disaster preparation.

- Yangon is not the most flood-threatened area in Myanmar. However, based on historical records, several major floods have occurred in the city.
- The two main types of flood in Yangon are (i) a combination of riverine flooding and flooding due to cyclone and storm surge; and (ii) localized floods (including urban flooding). The floods occurring in Yangon are caused not only by natural weather but also insufficient capacity of the drainage infrastructure.
- Several flood hazard maps of Yangon have been developed; these maps are beneficial for disaster preparation and loss reduction.
- A flood early warning system has been established and is effectively operating in Myanmar; a similar system for flash floods needs to be developed.

2.6.4 FIRE HAZARD

Over one-third of all fires in Myanmar every year occur in Yangon.

There are various reasons for the large number of urban residential fires, including building construction type, negligence, improper use or storage of cooking fuel, and inadequate electrical connections. Factory fires can be attributed to the same factors and, additionally, to the use of combustible material in the buildings.

Conditions in informal settlements contribute to the fire hazard and can impede the effort of firefighters in extinguishing fires. This issue can, at least in part, be addressed by the land use regulations and zoning that YCDC has been undertaking in recent years; this will be discussed more in detail later in this report.

Given the impact of fire and its frequent occurrence in the city, an outreach and education program could be beneficial. The program could inform the public on the ways to mitigate the hazard and steps to take in the event of a fire.

Fire in the aftermath of an earthquake is a major concern. The main cause of urban fire post-earthquake is the rupture of underground gas lines or electrical connections. Although not part of the scope of this report, a thorough review of utilities in Yangon is warranted. In the USA and Japan, gas shutoff valves were installed to automatically shut down the flow of combustible gas in the event of an earthquake and reduce the likelihood of fire in case of line rupture.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3. Exposure in Yangon

3.1 STUDY AREA

Yangon City has an urban area of approximately 600 km2 (YCDC, 2019) and a population of nearly 5.2 million people (Department of Population (DOP), 2014).

The administrative divisions of Myanmar are comprised of 15 states (or regions). Yangon City is part of the Yangon Region and consists of four districts. Yangon Region itself includes 45 townships. The districts are in turn divided into 33 townships (see Figure 57), and the townships are further divided into wards and village tracks (fourth-level administrative units), for which census data are collected. Key information regarding the study area is presented in Table 10.

FIGURE 57. Boundaries of the study area (YCDC, 2019)

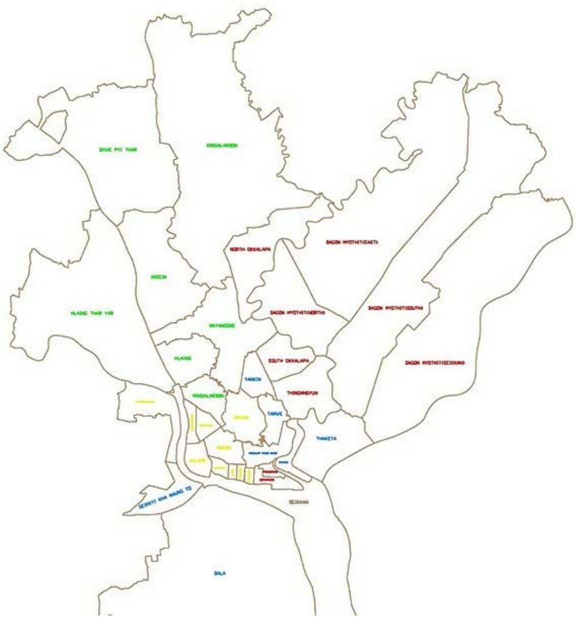
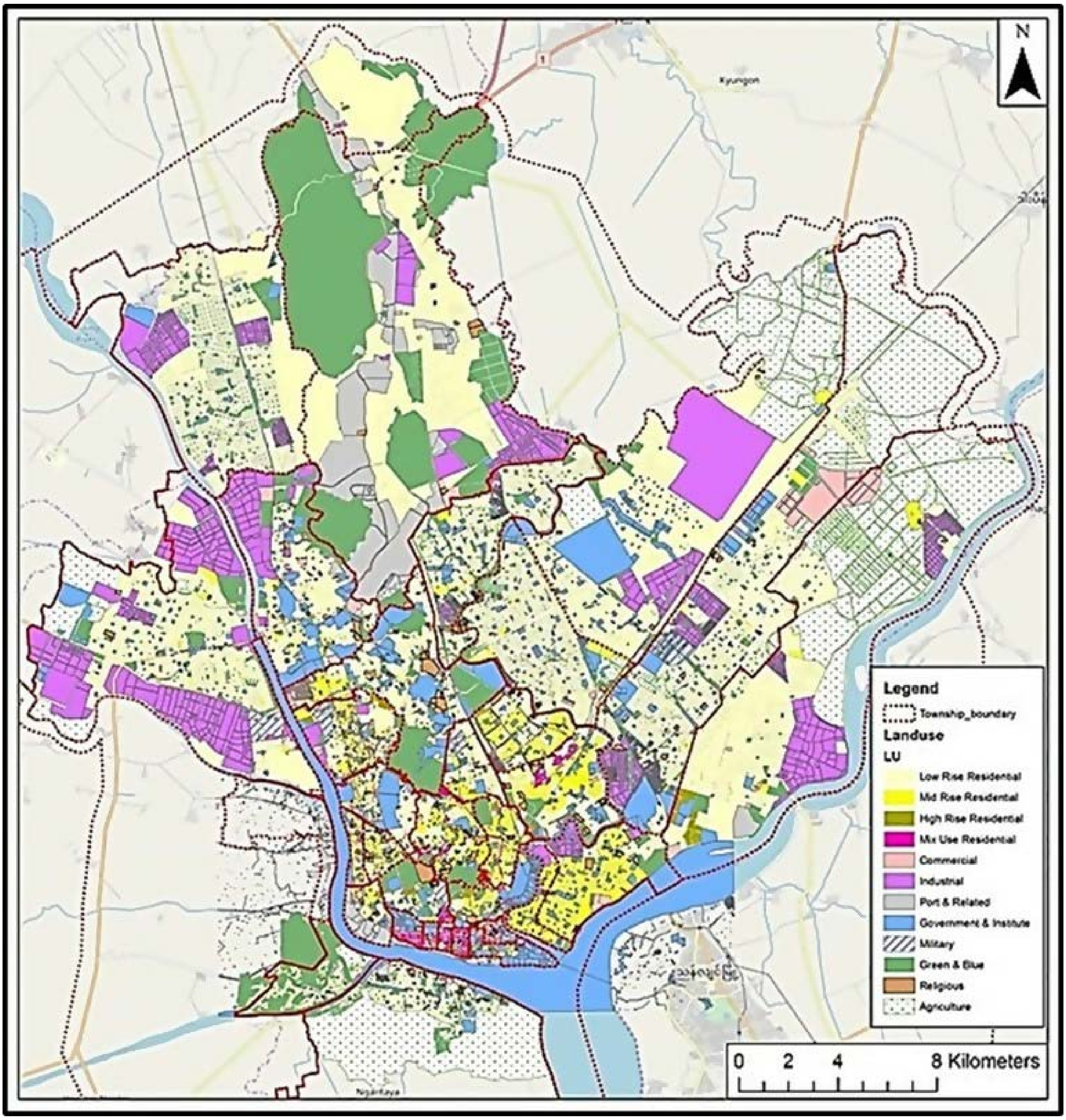


TABLE 10. Key data for the study area

DISTRICT	TOWNSHIPS	WARDS AND VILLAGE TRACKS	AREA, KM2 FROM MAP	POPULATION (2014 CENSUS)
North	7	145	295	2,111,251
East	7	194	329	1,612,575
South	9	163	304	960,944
West	10	116	31	504,583
Total	**33**	**618**	**959**	**5,189,353**

FIGURE 58. Spatial distribution of land use in Yangon (YCDC, 2019)



3.2 LAND USE AND DEVELOPMENT PATTERN

YCDC maintains the data related to land use in the city.

Figure 58 (YCDC, 2019) presents the spatial distribution of various types of land use in the city of Yangon. The aggregated types of use for the city are presented in Table 11 (YCDC, 2019)[17]. Residential units account for nearly a quarter of all land use, representing the largest component. There are a number of factories and industrial parks in the city, comprising 7 percent of land use. Government buildings account for a further 6 percent of land use in the city.

As part of the Joint Crediting Mechanism project between Yangon and Kawasaki City, Japan, some exposure data related to occupancy type and land use was collected and summarized (Nippon Koei Co. Ltd, 2016):

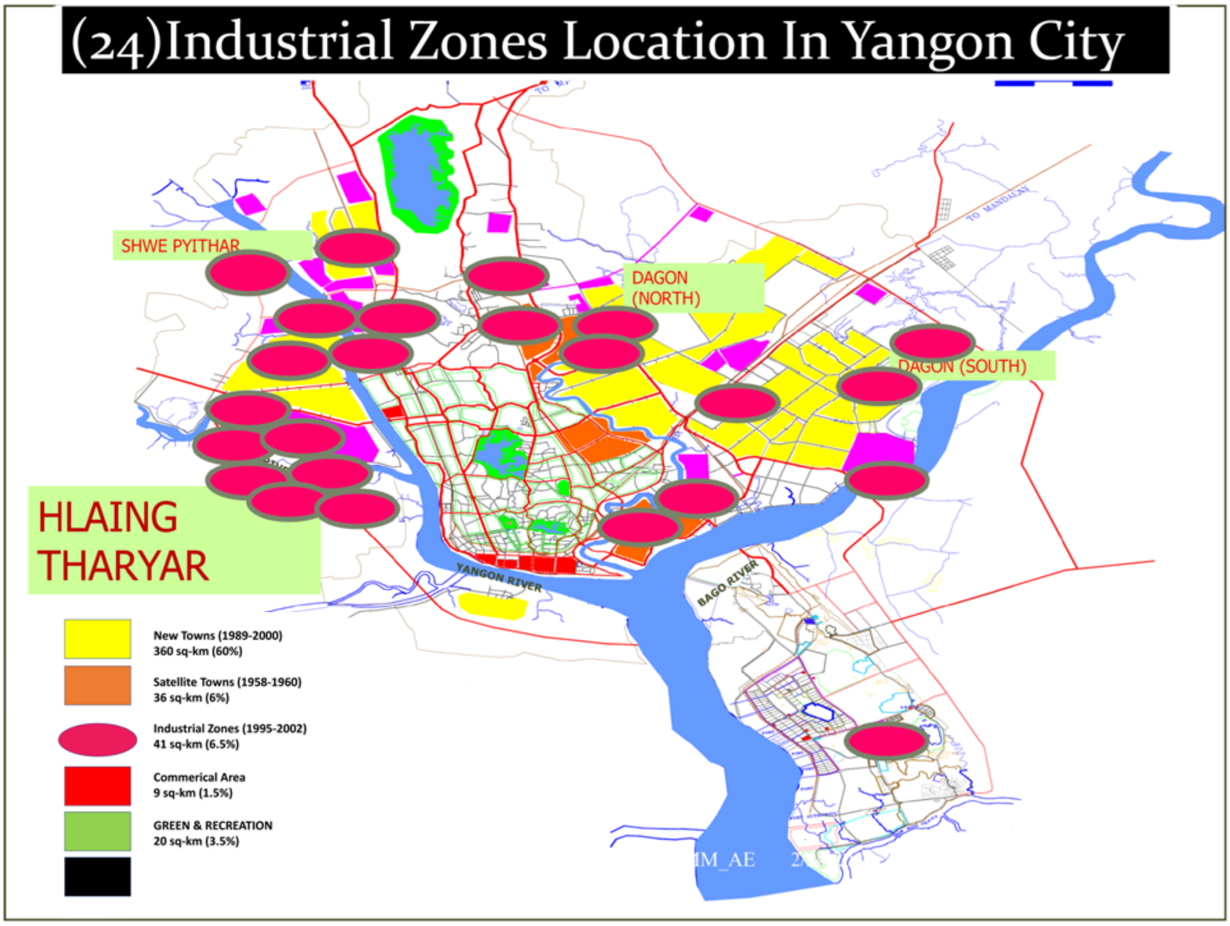
- There are 24 industrial zones in the city, housing almost 3,500 factories. The industrial zones are spread throughout the city (see Figure 59).
- There are more than 150 traditional markets and more than 50 modern markets in the city.
- There are more than 200 hotels in the city.
- A number of housing development projects, including low-income housing, are underway.

TABLE 11. Distribution of land area for various land uses (YCDC, 2019)

LAND USE	PERCENTAGE
Residential	24%
Industrial	7%
Green and blue	12%
Government and institutes	6%
Commercial	1%
Agriculture	13%
Mixed-use residential	1%
Military	1%
Ports	3%
Religious	1%
Roadways	20%
Other	12%

17. Due to rounding, percentages do not add up to 100.

FIGURE 59. Industrial zones in Yangon (adapted from Nippon Koei Co. Ltd, 2016)



3.3 BUILDING DISTRIBUTION AND MAPPING

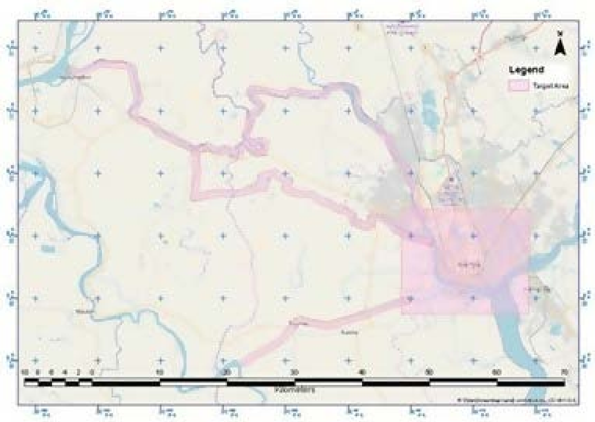
3.3.1 GENERAL INFORMATION ON THE BUILT ENVIRONMENT

Detailed exposure data from YCDC are not readily available.

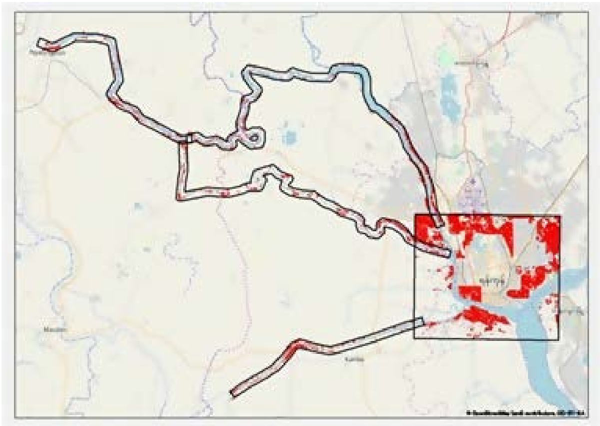
However, the following information was obtained from Yangon Myanmar Hotel (2019):

- Most downtown buildings from the colonial era are four- to six-story buildings with 14-ft ceilings and are of mixed-use (residential and commercial) occupancy.
- Eight-story apartment buildings are common in Yangon. Tall buildings are commonly referred to as "apartment buildings" if they do not have elevators or "condominiums" if they do. Until 2008, there was a requirement for buildings higher than 75 ft (or more than eight stories) to have elevators. This resulted in many buildings of eight or fewer stories being constructed. This threshold has now been changed to six stories (or 62 ft).
- The majority of 10-story and above high-rise buildings are residential (condominium); only a few are office towers in the downtown area.
- The tallest building in Yangon is a 25-story condominium building.
- Older satellite townships are mainly one- or two-story detached homes.
- There are informal settlements in some of the newer towns.

FIGURE 60. Extracting building information (Asia Air Survey, 2019)



Flight path



Extracting building information

Examples of extracted building footprint

3.3.2 LIDAR SURVEYS

The World Bank has been providing technical assistance to strengthen risk identification in Yangon City, including the development of a Digital Elevation (DEM) model for high-resolution airborne LiDAR topography data covering the City's southern townships and major rivers. Asia Air Survey (2019) has recently completed LiDAR scanning of a core area of 282 km2 within Yangon City (see Figure 60).

3.3.3 SATREPS PROJECT

As one of the components of the multiyear YTU/University of Tokyo project, an investigation was conducted of the feasibility of using data from remote sensing images to develop an exposure model for the city Murao et al. (2018).

The authors conducted a field survey of buildings in the Sanchaung Township and compared the results with the available imagery data. Next, field surveys in L atha and Pabedan Townships were conducted. Digitally-obtained data for the number of stories was then compared with the field data collected.

In the Sanchaung Township, 350 building Geographic Information System (GIS) points were available from JICA. The surveyed buildings were constructed using brick-noggin (BN), reinforced concrete (RC), or BT. Most buildings had one or two stories above the ground. Using aerial photographs and night imagery for the other two townships, building heights were extracted and compared with field surveys. By comparing the ratio of low- to mid-to-high-rise buildings, calibration factors for the digital imagery were established. Using this methodology, estimates of building height for the city based on digital imagery were computed (see Figure 61) (Murao et al., 2018). The SATREPS research team is currently working on obtaining building footprint data based on remote imaging.

3.3.4 ONEMAP MYANMAR

The Swiss Agency for Development and Cooperation (SDC) has developed the OneMap Myanmar web portal.

This platform allows for determination of Global Positioning System (GPS) coordinates of a point, as well as length and area calculations. The maps include information such as topography and street maps (see Figure 62) (SDC, 2019); OneMap can be used to develop an exposure model for the city.

FIGURE 61. Computed range of building heights based on digital imagery (Murao et al., 2018)

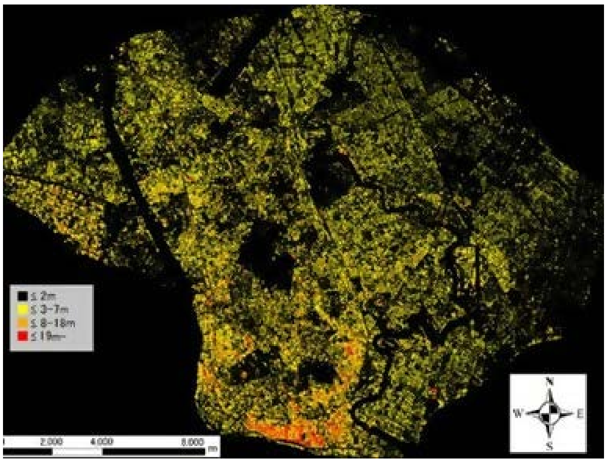


FIGURE 62. OneMap Myanmar (SDC, 2019)

3.4 BUILDING TYPOLOGY

3.4.1 INTRODUCTION

Building typology in Yangon falls into three main building types.

Figure 63 and Figure 64 present examples of building construction type and development patterns in Yangon, respectively. Although a variety of building frame types are to be found in the city, the main building types are as follows:

- Low-rise buildings (one to two floors above ground), built with BT, BN, and masonry bearing walls.
- Mid-rise (three to seven stories), with masonry bearing walls and RC frames with unreinforced masonry infill.
- High-rise (eight stories and more), with RC frames, RC shear walls, or a small number of steel frames.

RC frames, RC shear walls, and steel structures, if properly designed and constructed in compliance with the building code provisions for structural and fire regulations, are expected to perform well when subjected to natural hazards. However, other construction types have inherent vulnerabilities that are discussed briefly in this section. For these vulnerable types, heavier construction generally does poorly in earthquakes, whereas lighter-frame buildings are vulnerable to wind, flood, and fire.

3.4.2 BUILDING TYPE VULNERABILITY

BN buildings have performed poorly in past earthquakes, including the 2012 Thabeikkyin earthquake in Myanmar. During that event, many BN buildings either collapsed or sustained severe damage. BN buildings are primarily non-engineered and lack a defined load path, which contributes to their vulnerability.

BT buildings are light and allow for motion without inducing large stress on the members. As such, if constructed properly, it is anticipated that they would perform well in an earthquake. However, based on the light construction and roofing, they are susceptible to significant damage during cyclones. BT buildings could also suffer damage from flooding and are non-fire-resistant structures, so fire can spread rapidly.

Masonry buildings (unreinforced) have been the biggest contributor to loss of life and damage in past earthquakes. In some cases, because of inadequate connectivity, the walls fall out-of-plane and, in other instances, the entire building collapses due to brittle construction.

RC frame buildings with infill walls: infill walls are considered non-structural, or not load-resistant, but can in reality resist some external wind or earthquake forces. However, these walls will likely fail against larger forces. Since the failure is not uniform along the height of the building, they introduce irregular behavior that can lead to the collapse of the building.

Small industrial buildings can be structurally vulnerable. Often, the lower floor serves as a shop, while the upper floors are used as residential. In many cases, columns and walls of upper stories are terminated at the first-floor level to allow an open plan to facilitate business. This configuration can lead to the bottom story being less strong and less rigid than the floors above and could lead to the building collapsing in earthquakes or cyclones.

FIGURE 63. **Examples of common building types**

BT

BN

RC moment frame and infill walls

RC shear wall

Steel

Masonry wall

FIGURE 64. **Examples of development types**

Urban

High urban

High-rise, new development

Heritage zone

Market, commercial

Government

Small industrial

Informal

3.4.3 HERITAGE BUILDING VULNERABILITY

Yangon has the highest number of colonial buildings in Southeast Asia.

In 2012, the city imposed a 50-year moratorium on the demolition of buildings more than 50 years old (YCDC, 2019). The Yangon Heritage Trust (YHT) and the Association of Myanmar Architects (AMA) keep records of these buildings and monitors them for architectural maintenance and repairs. Of the nearly 2,000 heritage buildings in the city, YCDC is responsible for 189 buildings constructed before 1930 (see Figure 65) (JICA, 2013).

These 189 buildings are located in 21 of the city's townships. Among these structures, approximately half are religious sites, while the other half are government, commercial, or residential buildings.

Given the construction date of these buildings, they were not designed to comply with the earthquake or fire requirements specified in current codes. As such, they would be vulnerable to damage in the event of a major natural hazard.

3.4.4 INFORMAL SETTLEMENTS

Yangon's population is growing at a rate of nearly 2 percent annually; driven substantially by the internal migration of people seeking better economic opportunities.

The lack of housing and the high housing-to-wage ratio have led to more congested formal living arrangements and the spread of informal settlements (see Figure 66). These informal units are non-engineered and, in many instances, self-built and lacking a defined structural system, which makes them vulnerable to earthquakes, cyclones, floods, and fire.

To mitigate the spread of informal settlements, the Government has developed plans for low-income housing development in the city. In 2015, the Department of Human Settlement and Housing Development unveiled a large program to build low-income housing including over 10,000 units in the Dagon Seikkan Township (see Figure 67) (Myanmar Business Today, 2015).

FIGURE 65. Map of heritage buildings in the Yangon heritage zone (JICA, 2013)

These new buildings are structurally safer than informal dwellings. However, challenges remain as the cost associated with these units might be out of reach for many informal settlement dwellers. During the Myanmar Infrastructure Summit 2018, the Department of Urban and Housing Development estimated that, by 2040, more than one million units, including many low-income units, would be needed in Yangon to meet the expected population growth (Myanmar Infrastructure Summit, 2018).

3.4.5 OCCUPANCY TYPE

A key component of exposure development for an area such as Yangon is the determination of occupancy types. This is in part represented by land use. In addition, a more detailed data type of occupancy for the city is available. Data regarding religious, education, health, and market buildings for individual townships are available from Yangon City (2019). The aggregate of building data for each district is presented in Table 12.[18]

18. Religious buildings include pagodas, temples, churches, mosques, etc. Educational buildings include those for primary, middle, and secondary education. Health facilities include hospitals and clinics, both state-run and private.

FIGURE 66. Example of informal settlement (Forbes, 2016)

FIGURE 67. .Low-income housing in the Dagon Seikkan Township (Myanmar Business Today, 2015)

TABLE 12. Number of buildings of selected occupancy in Yangon (Yangon City, 2019)

DISTRICT	RELIGIOUS	EDUCATION	UNIVERSITY	HEALTH	MARKETS
North	587	254	4	135	32
East	654	237	4	41	27
South	651	246	4	39	24
West	584	215	4	38	24
Total	**2,476**	**952**	**6**	**253**	**107**

3.4.6 BUILDING HEIGHT LIMITS

JICA (2013) provides a summary of the current height limitations for various types of construction:

- For buildings located on frontage roads, the height cannot exceed twice the road width.
- Buildings are limited to six stories or less in the Reserved Areas for Shwe Dagon Pagoda.
- Buildings are limited to six stories or less in the Reserved Areas for Shwe Bone Pwint Pagoda.
- In the Tamwe Township, the height limit is 12 ft for first floors , and 9 ft for upper floors; six-story buildings need to have a pitched roof.

In addition, the new YCDC zoning plan will provide limits on the number of stories for new buildings in the downtown area with heritage buildings.

3.4.7 NUMBER OF STORIES

Constructions permits issued provide a useful snapshot into building trends.

Slightly over 2,900 construction permits were issued by YCDC for 2017–2018 (the last year for which data was available). The reference to half-stories indicates buildings with either partial basement or partial top-floor structure, as seen in Table 13 (YCDC, 2019). Notably, the data highlighted:

- Over 70 percent of new construction is concentrated in the North and East Districts.
- Approximately half of new construction is three stories or less.
- For taller buildings, most construction is concentrated in the East, South, and West Districts.

TABLE 13. Breakdown of permit application/approval statistics 2017-2018 (YCDC, 2019)

DISTRICT	STORIES													FENCES	TOTAL
	1–2	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5		
North	453	266	107	31	10	14	11	45	22	7	1	7	8	51	1,033
East	438	188	89	24	10	33	5	152	4	4	1	1	31	54	1,034
South	128	52	44	22	8	21	26	109	54	6	2	4	29	18	523
West	44	50	38	19	5	5	4	68	25	4	3	3	28	18	314
Total	**1,063**	**556**	**278**	**96**	**33**	**73**	**46**	**374**	**105**	**21**	**7**	**15**	**96**	**141**	**2,904**

3.4.8 CONSTRUCTION TYPE

In 2014, countrywide census data were collected.

DOP provides population and housing census reports for various regions. Data from the 33 townships was extracted for the Yangon Region (DOP, 2015) and presented in this section. Table 14 presents the types of housing units, with data derived from approximately 1.8 million households listed as part of the census.

It is shown that for the city, about a quarter of housing units are apartments or condominiums, as described in 3.1.1 above, mainly concentrated in the West District and most likely constructed using RC and to a lesser extent, masonry. Wooden and bamboo housing account for over 50 percent of units. Approximately 10 percent of buildings are brick (masonry), and another 10 percent are a combination of brick and wood.

Table 15 presents the construction data based on the type of exterior walls, flooring, and roof, respectively. Of note are the following key points:

- Nearly 6–12 percent of buildings use dhani, theke, or in leaf for wall or roofing. This traditional construction is inexpensive but also non-engineered.
- Approximately 50 percent of buildings have wood or bamboo exterior walls, and close to 35 percent have concrete or brisk walls, consistent with data in Table 14.
- Nearly 65 percent of buildings have wood or bamboo floors, while 33 percent have concrete or brick floors. This indicates that many of the semi-pacca houses use wood or bamboo flooring.
- Nearly 95 percent of buildings use light-frame roofing, while the remainder uses heavy concrete or brick roofs. Corrugated metal sheet is the most common type of roofing.

TABLE 14. Types of housing units (DOP, 2015)

DISTRICT	APARTMENT OR CONDOMINIUM	BUNGALOW OR BRICK	SEMI-PACCA	WOODEN HOUSE	BAMBOO	HUT, 2–3 YEARS	HUT 1 YEAR	OTHER
North	16.6%	8.8%	13.3%	43.1%	15.3%	0.9%	0.7%	1.2%
East	10.9%	11.4%	11.9%	49.4%	13.2%	1.0%	0.7%	1.5%
South	38.4%	5.2%	8.4%	35.7%	10.6%	0.5%	0.4%	0.8%
West	65.1%	7.3%	7.2%	15.8%	3.6%	0.2%	0.1%	0.7%
Total	**23.5%**	**8.8%**	**11.4%**	**41.1%**	**12.7%**	**0.8%**	**0.6%**	**1.2%**

TABLE 15. Types of construction material (DOP, 2015)

DISTRICT	DHANI, THEKE, OR IN LEAF	BAMBOO	EARTH	WOOD	CORRUGATED SHEET	TILE, BRICK, OR CONCRETE	OTHER
				EXTERIOR WALL			
North	5.3%	32.0%	0.1%	23.7%	1.6%	36.0%	1.4%
East	6.0%	34.1%	0.1%	24.0%	1.5%	32.8%	1.5%
South	5.8%	33.7%	0.1%	25.8%	1.5%	31.6%	1.5%
West	6.6%	36.5%	0.1%	25.2%	1.5%	28.6%	1.7%
Total	**5.9%**	**34.1%**	**0.1%**	**24.7%**	**1.5%**	**32.2%**	**1.5%**
				FLOOR			
North	--	11.7%	0.6%	50.3%	--	35.9%	1.4%
East	--	13.1%	0.6%	51.5%	--	33.3%	1.4%
South	--	12.8%	0.6%	52.9%	--	32.2%	1.4%
West	--	14.8%	0.7%	53.5%	--	29.6%	1.4%
Total	**--**	**13.1%**	**0.6%**	**52.1%**	**--**	**32.7%**	**1.4%**
				ROOF			
North	10.2%	0.2%	--	0.2%	82.7%	6.3%	0.3%
East	11.2%	0.2%	--	0.2%	82.9%	5.1%	0.3%
South	11.0%	0.2%	--	0.2%	84.1%	4.2%	0.4%
West	12.6%	0.2%	--	0.2%	84.3%	2.4%	0.3%
Total	**11.3%**	**0.2%**	**--**	**0.2%**	**83.5%**	**4.4%**	**0.3%**

3.5 FUTURE EXPOSURE: POPULATION GROWTH AND URBANIZATION

3.5.1 INTRODUCTION

Yangon is a dynamic metropolis that is undergoing growth and change.

This section presents a brief discussion of the topic, as it relates to future exposure and the associated challenges to the city's resilience. A more detailed discussion of urbanization and city planning is presented later in the report.

3.5.2 POPULATION GROWTH

The city has been growing at a consistent rate of approximately 2 percent annually. This trend is shown in Figure 68 (World Population Review, 2020). Using the same trend line, the city population is anticipated to grow to over seven million by 2035. However, given the accelerated urbanization of the country, this number might underestimate the actual pattern. Thus, it is critical to plan for providing adequate infrastructure, including safe housing, for the current residents and the additional two million people expected.

3.5.3 URBANIZATION IN YANGON

The World Bank examined the urbanization trends in Myanmar, with a focus on Yangon (World Bank 2019). A key observation is that, to reach middle-class status, the country would need to undergo urbanization, because growth in the cities provides an opportunity for vibrant economic growth and allows for creative entrepreneurship. Based on a literature review, the report presented the following statistics:

- Between the years 2009 and 2014, over 80 percent of the population growth in Yangon is attributed to internal migration (43 percent of the total for the country), as people sought better economic opportunities.
- Over 90 percent of Yangon's economy is based on the industry and service sectors.
- Yangon's urban population is 70 percent of the total population—by far the largest percentage in the country.
- The urban expansion in Yangon is presented in Figure 69. In Yangon, the rate of spatial expansion has been 24 m2 of land area per individual resident, implying that new residents are being accommodated through more congested occupancy in existing structures and through the expansion of informal settlements.

FIGURE 68. City population growth trend (World Population Review, 2020)

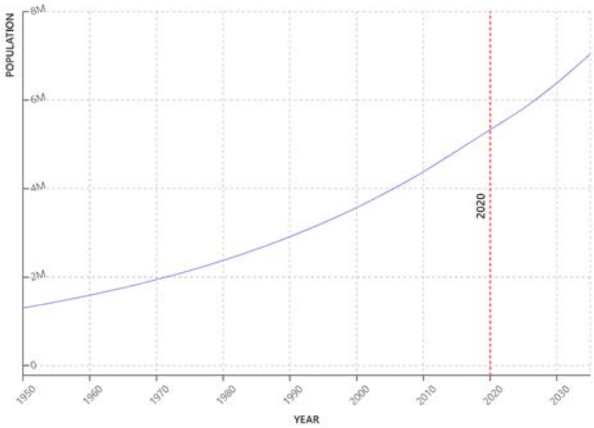
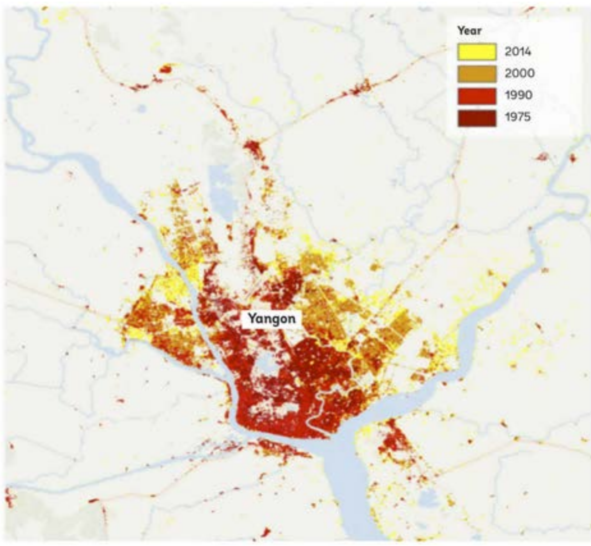


FIGURE 69. Yangon urban expansion, 1974–2014 (WB, 2019)



3.6 DISCUSSION

3.6.1 EXPOSURE DATA

A significant amount of data related to natural hazards is available for Yangon.

However, related data for the built environment and population exposure are relatively limited and fragmented. In recent years, several major projects have begun and are still ongoing, aimed at obtaining more detailed data and statistically organizing this information.

3.6.2 LIDAR SURVEYS

The data has been used to support the development of flood risk models for greater Yangon and Yangon City, in collaboration with the Netherlands Enterprise Agency (Rijksdienst voor Ondernemend Nederland - RVO). Useful building information can be derived from the LiDAR dataset, such as the extracted building footprint shown in Figure 60.SATREPS project

Building height range may be used to estimate construction type.

As part of a multiyear YTU/University of Tokyo project, the researchers have utilized digital imagery and calibrated the data with the results from field surveys to determine the range of building heights. This is a significant outcome, as the building height range (low-, mid-, or high-rise) construction can be closely determined using digital imagery. The research team is also working on computing building footprints based on aerial data. The outcome of this project, when available, will have a significant impact on the development of the city's built environment and exposure.

3.6.3 2017–2018 CONSTRUCTION PERMITS

Slightly over 2,900 construction permits were issued in 2017–2018.

To enhance the city's resilience, it is important that a rigorous program of plan checking by desk review and construction inspection in the field be implemented to ensure that (i) the buildings are designed according to the code and YCDC requirements, and (ii) construction quality control meets the design's intent.

3.6.4 2014 CENSUS DATA

The 2014 census data can be used to estimate the construction typology in Yangon.

Review and analysis of the census data showed that:

- Nearly 6–12 percent of buildings use dhani, theke, for wall or roofing. This type of construction provides no mechanism for the load path to resist earthquake loading, and has no resistance to cyclone forces or heavy rainfall. Unless properly treated, it is also vulnerable to fire damage.
- Wood and bamboo construction accounts for nearly 55 percent of all construction, while concrete and masonry account for 35 percent. Wood buildings are expected to perform well in earthquakes because they are light and have higher inherent structural damping. Masonry buildings have performed poorly in past earthquakes. Similarly, concrete buildings that are not designed properly do not perform well in earthquakes.
- Wood and bamboo buildings are vulnerable to wind hazard; this is exacerbated by the prevalent use of light-framed roof material. Unless adequate anchor connections to the foundation are provided, the buildings can separate from their foundations during windstorms. Similarly, roof hold-downs are necessary to prevent the uplift of wood or corrugated metal material from the building.
- Wood and bamboo buildings would be vulnerable to flood hazard and, depending on the inundation depth, may have to be evacuated and possibly rebuilt.
- Wood buildings are vulnerable to fire hazard. It is critical to either use fire retardant material in the construction or to ensure that there are adequate fire alarm/warning mechanisms and firefighting capacity available to limit damage and casualties.

3.6.5 BUILDING TYPES AND DEVELOPMENT PATTERNS

A number of building types such as masonry, BN, BT, and RC frame with infilled masonry are common in the city.

These construction types are vulnerable to one or more natural hazards, as evident in their past performance in earthquakes, cyclones, floods, and urban fires. The city also has a large number of heritage buildings that were constructed during the period where structural safety to natural hazards was not well understood, making these important structures vulnerable. Finally, a large number of houses in informal settlements lack defined structural systems and are vulnerable to all the natural hazards discussed in this report.

3.6.6 FUTURE TRENDS

Yangon is experiencing growth in both population and built environment.

Accordingly, it is important to maintain a database to allow for the search and processing of inventory data for the built environment, as well as a population exposure database that can be updated and used for disaster planning and response.

4. Fragility Functions

4.1 OVERVIEW

Damage states (DSs) are defined to quantify the response of buildings and other infrastructure to natural hazards.

The Federal Emergency Management Agency (FEMA) Hazus program (FEMA, 2019) addresses DSs for earthquakes, wind, floods, and fire after earthquakes. To assess the performance of a building and allow comparisons among buildings of different construction and age, fragility functions are developed. A fragility function denotes the probability of exceeding a DS for a given hazard input parameter. The impact of strengthening measures can then be assessed by the shift in values of the fragility functions away from damage. Although different expressions can be used to idealize fragility functions, the use of log-normal distribution is the most common approach. Fragility functions can be developed using a number of techniques, including:

EMPIRICAL: damage surveys are conducted in the aftermath of a natural hazard event. The data is then compiled and statistically analyzed, and fragility functions are developed. This was the basis of the approach taken in the aftermath of the 2010 Haiti earthquake, and was used to develop fragility functions for the country. This also shows the importance of having a uniform damage assessment form and collecting and archiving damage assessment reports.

EXPERIENTIAL: citizens are interviewed about a past event and, based on their anecdotal recollections, different DSs are assigned to the past damage. The DSs are then correlated to the estimated intensity of hazard at the observation site. This technique is being used by the YTU/University of Tokyo team to develop flood fragility functions based on the 2008 Cyclone Nargis.

EXPERT ELICITATION: experts and engineers are interviewed, and DSs of the past major events are quantified and then linked to the hazard intensity. This was the basis for the initial release of FEMA Hazus (FEMA, 2019).

EXPERIMENTAL: laboratory tests of buildings and their components (structural and non-structural) are performed. Most testing is conducted through earthquake simulators, wind tunnels, channel beds, or fire labs, although other test methods could also be utilized. Tests are conducted in an incremental manner, and damage for each level of intensity is documented. The data is then used to develop a discrete fragility function and curve-fitted to obtain the continuous fragility functions. This is the methodology used in the development of FEMA P-58 (FEMA, 2012).

ANALYTICAL: for a given building type, a number of archetypes are selected. The archetypes are then modeled and subjected to nonlinear (dynamic or static) analysis until building collapse is reached. The analysis is repeated for each archetype, and the results are aggregated for a given building type. Log-normal curves are then fit to develop the fragility function. This method can be used for building types (e.g., RC frame) and components (e.g., a joint connection) in a building. This is the methodology used in the development of FEMA P695 (FEMA, 2009) and FEMA P-795 (FEMA, 2011).

HYBRID: a combination of empirical and analytical techniques.

TABLE 16. .DS description for BM buildings (FEMA, 2003a)

DS	DESIGNATION	DESCRIPTION
DS1	Slight	Diagonal, stair-step hairline cracks on masonry wall surfaces; larger cracks around door and window openings in walls with a large proportion of openings; movements of lintels; cracks at the base of parapets.
DS2	Moderate	Most wall surfaces exhibit diagonal cracks; some of the walls exhibit larger diagonal cracks; masonry walls may have visible separation from diaphragms; significant cracking of parapets; some masonry may fall from walls or parapets.
D#	Extensive	In buildings with a relatively large area of wall openings, most walls have suffered extensive cracking; some parapets and gable-end walls have fallen; beams or trusses may have moved relative to their supports.
DS4	Complete	Structure has collapsed or is in imminent danger of collapse due to in-plane or out-of-plane failure of the walls; approximately 15% of the total area of unreinforced masonry (URM) buildings with complete damage is expected to collapse.

The FEMA Hazus methodology has been widely used around the world and adapted to many countries to account for their particular construction types. As the log-normal fragility functions are defined by a mean and a standard deviation, it is critical to modify these parameters to account for local construction practices. Much research has been undertaken worldwide to characterize building construction and allow for the development of modified fragility functions to suit the local environment. For example, as part of the Earthquake Engineering Research Institute's World Housing Encyclopedia (2019) project, local architects and engineers developed over 100 construction profiles for 40 countries. Although Myanmar is not explicitly included, a number of construction types such as masonry, concrete, and timber from other developing countries are applicable to Yangon as well. As part of developing the Global Earthquake Model (GEM, 2019) taxonomy model, research by Pitilakis et al. (2014) produced a large number of fragility functions for various building types.

4.2 EARTHQUAKE FRAGILITY

The seismic fragility functions applicable to construction types in Yangon are described in this section.

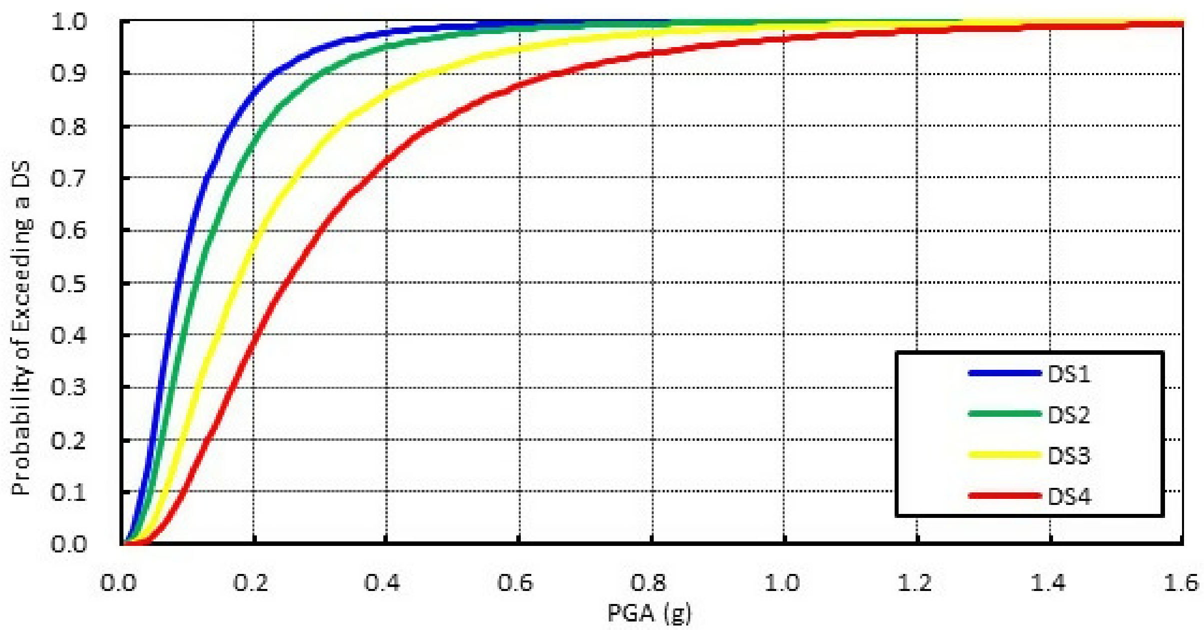
4.2.1 BRICK MASONRY BUILDINGS

Some buildings in the city use brick masonry (BM) bearing walls for construction.

This was a common construction type in the early to mid-1900s. FEMA (2003a) defines structural DSs for this type of construction as listed in Table 16.

FEMA (2003a) also includes fragility parameters for URM buildings in California. As an illustration, these parameters were selected and then modified to account approximately for quality of construction and source of seismicity in a location similar to Yangon. The resulting fragility functions (for case of pre-seismic code design) are presented in Figure 70. Note that an earthquake with PGA of 0.4, an event that can be expected in Yangon, would result in extensive damage in nearly 70 percent of URM buildings, and some of these structures could collapse.

FIGURE 70. Example of fragility functions for BM buildings



4.2.2 BRICK-NOGGIN BUILDINGS

BN buildings are a unique construction type in which a wood frame is constructed, and then brick is used to fill the gaps in the frame.

The brick walls may be covered by tile. Typically, there is no mechanical connection between the brick and wood frame, and mortar is used to hold the brick in place.

The 2012 M6.8 Thabeikkyin earthquake resulted in 26 fatalities and significant damage. Following the earthquake, researchers from the Civil Engineering Department at the Mandalay Technological University (MTU) conducted a preliminary assessment. As part of the assessment, damage data, including the level of damage, were obtained from the General Administrative Department (GAD). Four building types were identified in the impacted area: RC, BN, masonry, and wood construction (New et al., 2018). In addition, three DSs were defined (see Table 17), and the amount of each type of building and the rate of each type falling in various DSs were identified (see Table 18).

Of the 701 BN buildings, 371 (over 50 percent) experienced moderate to heavy damage, making this and masonry the most vulnerable building types.

Next, based on the results of interviews, the Medvedev–Sponheuer–Karnik seismic intensity of the earthquake for each site was estimated. Finally, based on the distribution in each DS and the associated intensity, the fragility functions for the BN buildings were developed (see Figure 71) (New et al., 2018).

TABLE 17. **DSs for BN buildings (New et al., 2018)**

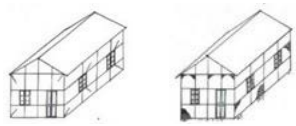
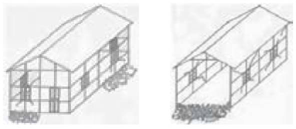
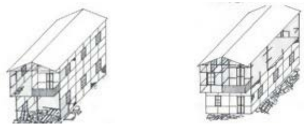
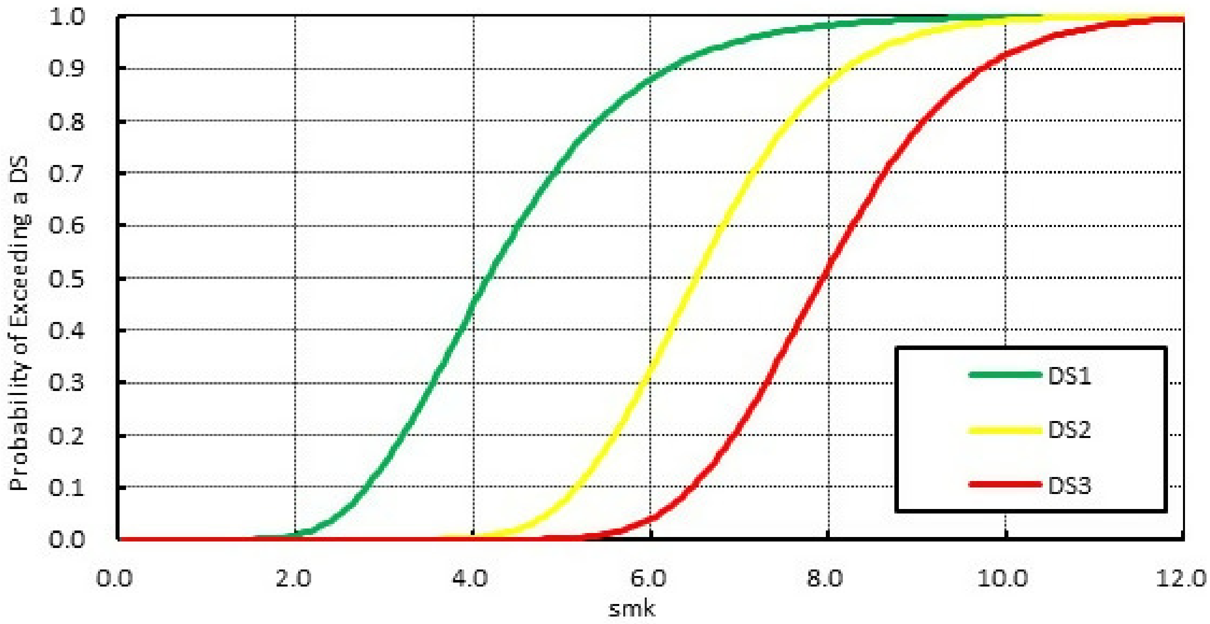
DS	DEFINITION	ONE-STORY	TWO-STORY
1	Slight		
2	Moderate		
3	Heavy		

TABLE 18. **Building construction types and observed damage (New et al., 2018)**

DAMAGE	BN	RC	WOOD	MASONRY
None	65	2	1,236	1
Slight	265	12	428	0
Moderate	276	5	102	2
Heavy	95	3	52	4

FIGURE 71. Fragility functions for BN buildings (New et al., 2018)



4.2.3 REINFORCED CONCRETE BUILDINGS

The city's downtown is small in area but has a large population density, and most of the construction in this area is RC.

Nwe et al. (2016) studied 1,103 buildings in the downtown area with the following characteristics:

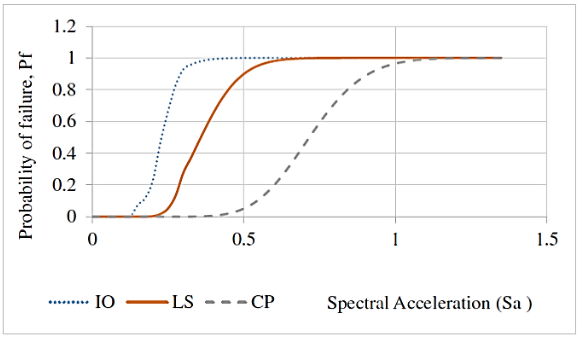
- RC moment frame and infill masonry: 731; brick: 371.
- Three stories or less: 474; four to six stories: 504; seven to eight stories: 110; over eight stories: 15.

Most reinforced concrete buildings in Yangon can be classified as mid-rise. Additionally, the buildings are rectangular and have symmetrical floor plans for two-unit apartments and asymmetrical for one-unit apartments.

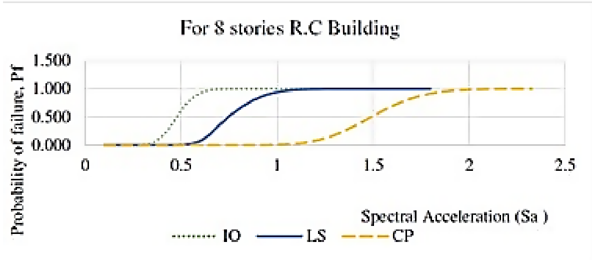
The authors selected three-, six-, and eight-story buildings, both symmetrical and asymmetrical, as archetypes. Next, finite element models of the buildings were prepared and subjected to nonlinear static analysis. The authors determined the probability of failure for each archetype (Figure 72).

Note that at a PGA of 0.4 g (spectral acceleration of 1.0 g), the three-story building, and the six-story asymmetric building could experience collapse. There would be significant damage to the eight-story building.

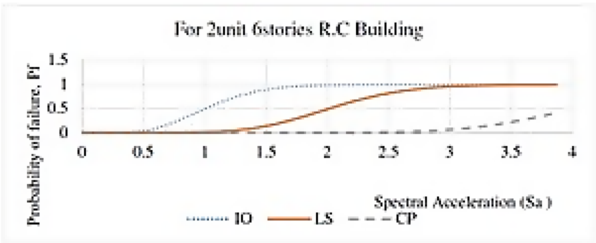
FIGURE 72. Fragility functions for BN buildings (Nwe et al., 2016)



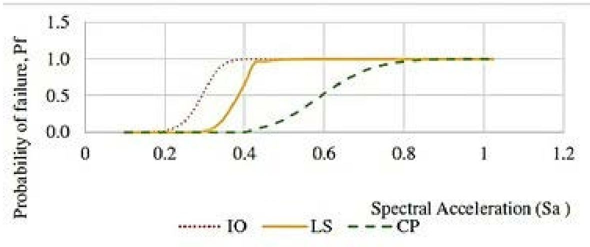
Three-story



Eight-story

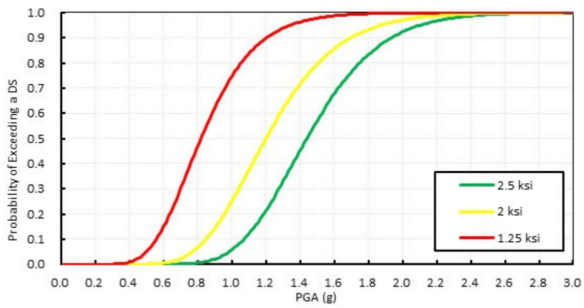


Six-story symmetrical

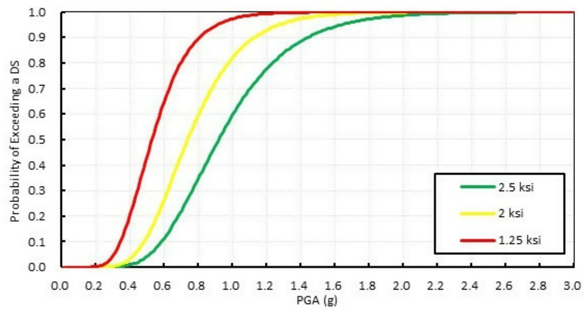


Six-story asymmetrical

FIGURE 73. DS4 fragility functions, various material properties



Low-rise



Mid-rise

As part of the joint UTY/University of Tokyo research (SATREPS, 2016), fragility functions for RC buildings in downtown Yangon have been developed.

Gadagamma et al. (2018) studied the fragility for RC buildings in the city. The authors looked at 39 low-rise (two to three stories) and 15 mid-rise (five to six stories) buildings during 2014 and 2015. The buildings are regular in plan, with one commercial building and the rest residential units. The as-built information was collected from YCDC, and three concrete strengths (1.25, 2.0, and 2.5 ksi) were used in the analysis. The building models were prepared and subjected to nonlinear static analysis.

Figure 73 presents the fragility functions for the complete DS (collapse) for low- and mid-rise buildings and with material properties. At a PGA of 0.6 g (approximate value for a maximum event for the city), the probability of collapse is smaller for higher concrete strength. For example, in case of mid-rise buildings, the probability of collapse increases from 10 percent to more than 60 percent when inferior concrete is used.

Hara et al. (2018) studied the fragility for RC buildings in Yangon based on the actual existing conditions. The authors defined DSs of buildings according to FEMA (2003a) (see Table 19) and conducted pushover analysis for RC buildings. The nominal lateral load capacity of buildings was estimated based on the Uniform Building Code (1997), which is the basis for the 2012 MNBC. To determine the expected values of material strength, 33 reinforcing bars of 6, 8, 10, and 25 mm reinforcement samples were taken from construction sites. The authors observed that (i) the reinforcement diameter on the bars was, on average, 10 percent smaller than nominal; (ii) there was corrosion of reinforcement; and (iii) the measured yield strength was 300 MPa for ASTM Grade 40 reinforcement, and there was large variation in material strength among samples. In interviews with YCDC, the authors noted that (i) for new RC buildings, concrete has a nominal compression strength of 13.8 MPa (concrete strength of 2 ksi), and reinforcement has a nominal yield of 276 MPa (Grade 40); (ii) defective construction occurs frequently due to the lack of highly-skilled construction workers and, in many cases, there is exposed reinforcement due to lack of concrete cover; and (iii) concrete has low strength and Young modulus due to a lack of good mixing protocol, as well as poor-quality sand and aggregate.

Drawings for 54 buildings were acquired, and 20 of these buildings (six two-story, seven three-story, and seven seven-story) were analyzed. The analysis accounted for actual reinforcement dimension and corrosion, as well as concrete and reinforcement properties. The pushover curves for three-story buildings are presented in Figure 74 (Hara et al., 2018). As shown in the Figure, the location of corrosion and reduction in reinforcement area results in a significant decrease in the building's lateral capacity. The fragility functions for three- and seven-story buildings, with various degrees of reduction in reinforcement, are presented in Figure 75 (Hara et al., 2018). As shown in the Figure, the location of corrosion and reduction in reinforcement area results in a significant increase in the building's fragility. For example, the fragility functions for DS4 were developed for selected cases (see Figure 76). For a three-story building, with a spectral displacement of 8 cm, the probability of exceeding DS4 is increased from 60 percent to 82 percent, while for a seven-story building, with a spectral displacement of 12 cm, the probability of exceeding DS is negligible for intact reinforcement by 40 percent and 95 percent for cases of 10 percent and 20 percent reduction in reinforcement size due to undersize or corrosion.

4.2.4 BAMBOO AND TIMBER BUILDINGS

As part of the joint UTY/University of Tokyo research (SATREPS, 2016), fragility functions for wood-bamboo (BT) construction in Yangon are under development.

4.3 CYCLONE FRAGILITY

4.3.1 OVERVIEW

Studies on the cyclone - i.e., wind - fragility function of buildings in Myanmar have not been performed yet.

However, existing work on fragility functions of buildings for hurricanes or typhoons in other countries could be applicable and referenceable to the buildings environment of Myanmar. Therefore, some fragility functions developed in the USA and Asia are detailed in the following sections.

4.3.2 FEDERAL EMERGENCY MANAGEMENT AGENCY

In the USA, FEMA Hazus developed a large number of hurricane fragility functions according to building types, component items, connection specifications, roof shapes, and terrains (FEMA, 2013b).

It considers many damage scenarios for buildings due to wind-induced pressure, which affects windows, doors, walls, roofs, glazing, and connections. Then, by comparing the load to the resistance, the probabilities of hurricane-induced damage are analyzed according to several DSs, as shown in Table 20 using residential buildings as an example.

Five DSs are generally set for a fragility function: (i) no damage or very minor damage; (ii) minor damage; (iii) moderate damage; (iv) severe damage; and (v) destruction. Based on the prescribed damage thresholds, probability distributions of each DS according to wind intensity, or peak gust wind speed, were analyzed, and fragility functions were obtained as shown in Figure 77. Fragility functions of buildings (enveloped), window, roof cover, roof sheathing, and roof-wall connectionsare shown; damage scenarios of window and roof cover govern the building fragility function for this type of residential building.

TABLE 19. DS description for RC buildings (no infills) (FEMA, 2003a)

DS	DESIGNATION	DESCRIPTION
DS1	Slight	Flexural or shear type hairline cracks in some beams and columns near joints or within joints.
DS2	Moderate	Most beams and columns exhibit hairline cracks. In ductile frames, some of the frame elements have reached yield capacity indicated by larger flexural cracks and some concrete spalling. Non-ductile frames may exhibit larger shear cracks and spalling.
D3	Extensive	Some of the frame elements have reached their ultimate capacity indicated in ductile frames by large flexural cracks, spalled concrete, and buckled main reinforcement; non-ductile frame elements may have suffered shear failures or bond failures at reinforcement splices, or broken ties or buckled main reinforcement in columns, which may result in partial collapse.
DS4	Complete	Structure is collapsed or in imminent danger of collapse due to brittle failure of non-ductile frame elements or loss of frame stability.

FIGURE 74. Pushover curve for three-story buildings (Hara et al., 2018)

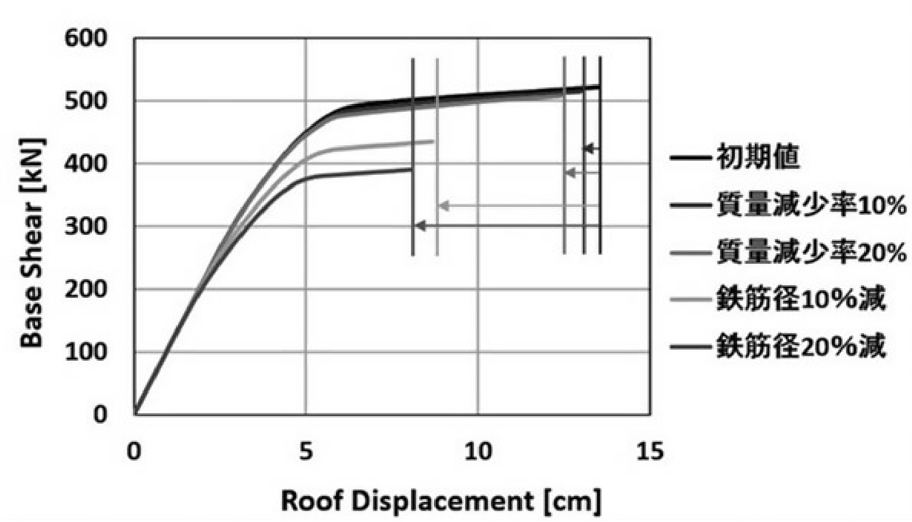


FIGURE 75. Fragility functions for three- and seven-story buildings, with actual reinforcement (Hara et al., 2018)

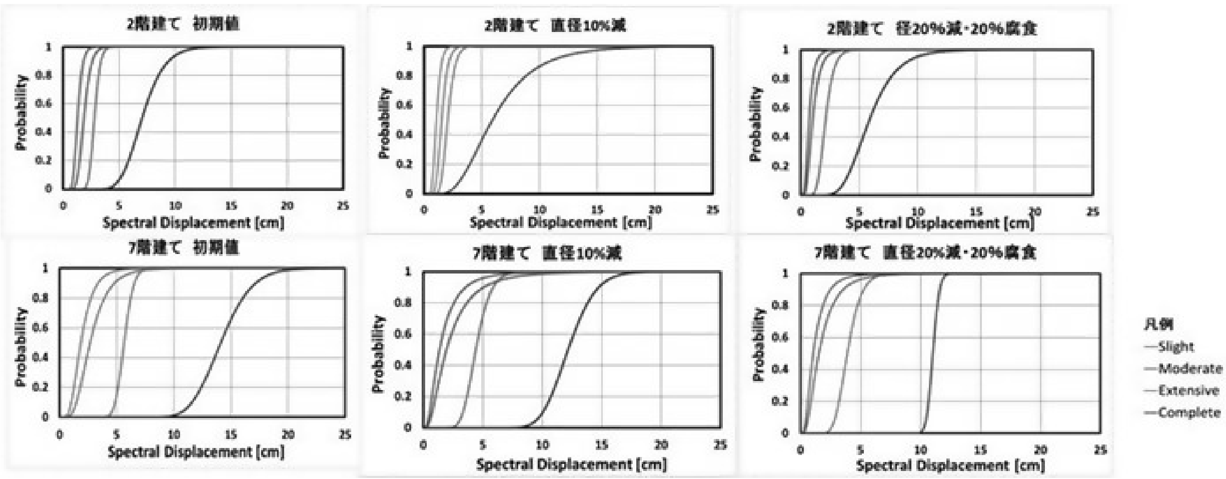
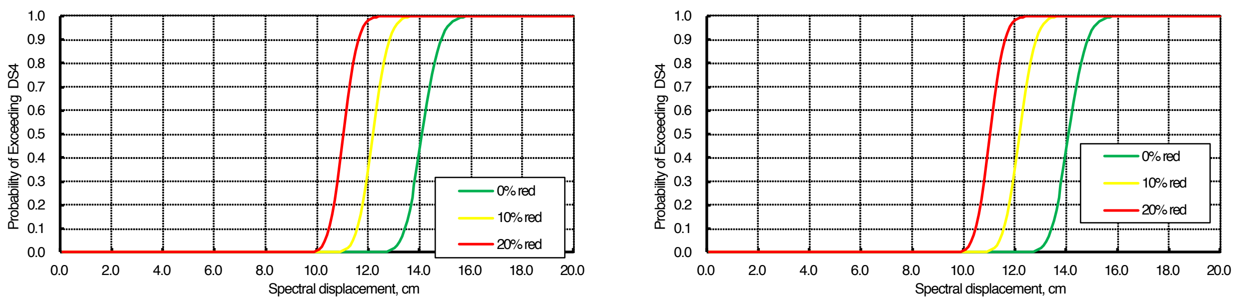


FIGURE 76. DS4 fragility functions for selected cases (adapted from Hara et al., 2018)



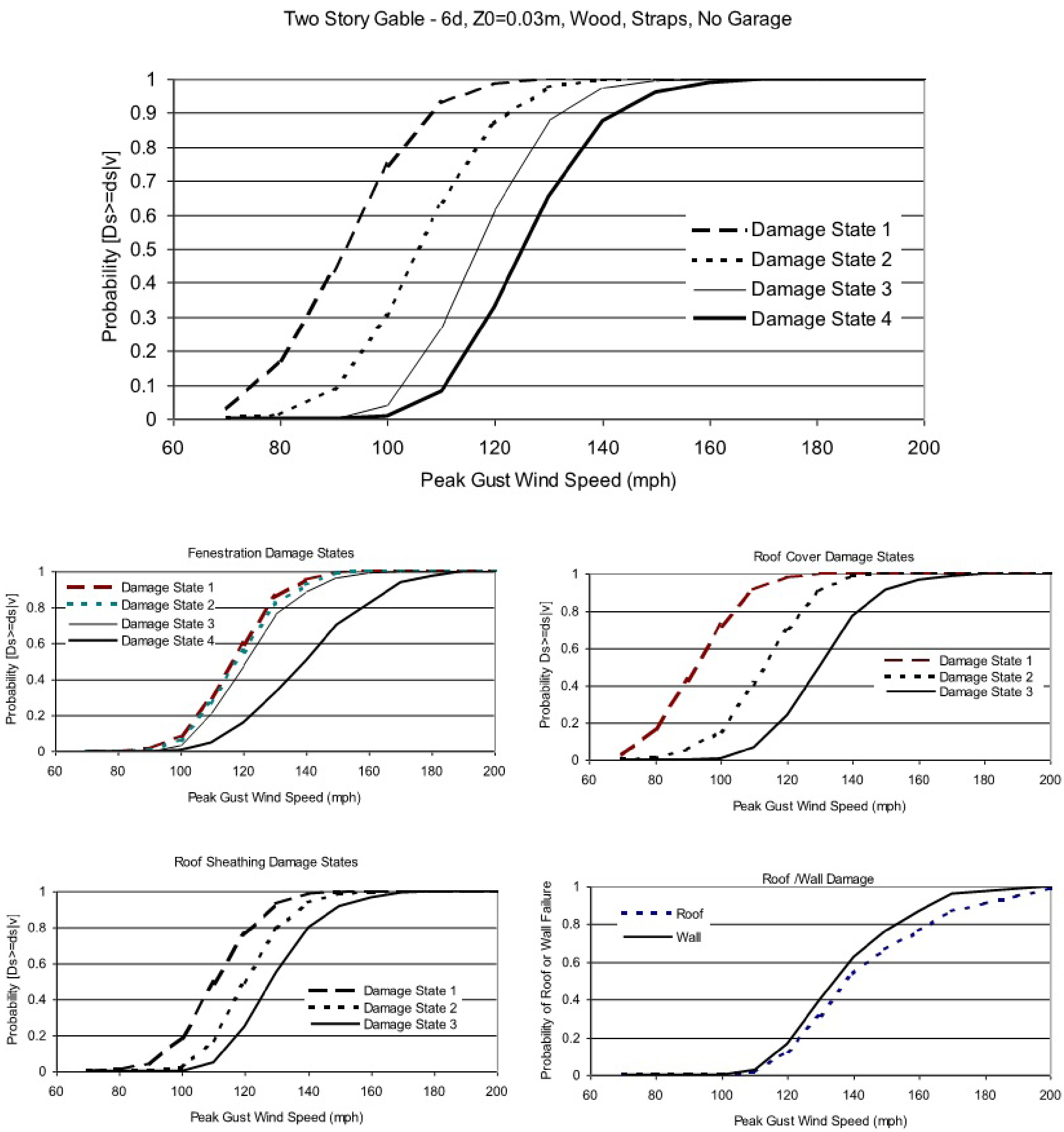
Three-story

Seven-story

TABLE 20. Hurricane DSs for a residential building (FEMA, 2013b)

DS	QUALITATIVE DAMAGE DESCRIPTION	ROOF COVER FAILURE	WINDOW DOOR FAILURE	ROOF DECK	MISSILE IMPACTS ON WALLS	ROOF STRUCTURE FAILURE	WALL STRUCTURE FAILURE
0	**No damage or very minor damage** Little or no visible damage from the outside. No broken windows or failed roof deck. Minimal loss of roof cover, with no or very limited water penetration.	≤ 2%	No	No	No	No	No
1	**Minor damage** Maximum one broken window, door, or garage door. Moderate roof cover loss that can be covered to prevent additional water from entering the building. Marks or dents on walls requiring painting or patching for repair.	> 2% and ≤15%	One window, door, or garage door failure	No	< 5 impacts	No	No
2	**Moderate damage** Major roof cover damage, moderate window breakage. Minor roof sheathing failure. Some resulting damage to building interior from water.	> 15% and ≤ 50%	> 1 and ≤ the large of 20% and 3	1 to 3 panels	Typically 5 to 10 impacts	No	No
3	**Severe damage** Major window damage or roof sheathing loss. Major roof cover loss. Extensive damage to interior from water.	> 50%	> the larger of 20% and 3 and ≤50%	> 3 and ≤ 25%	Typically 10 to 20 impacts	No	No
4	**Destruction** Complete roof failure and/or failure of wall frame. Loss of more than 50% of roof sheathing.	Typically > 50%	> 50%	> 25%	Typically > 20 impacts	Yes	Yes

FIGURE 77. Hurricane fragility functions of a residential building (FEMA, 2013b)



4.3.3 TYPHOON FRAGILITY ASSESSMENT

A series of research projects were conducted on typhoon fragility for an industrial building in South Korea (Ham et al., 2009; Lee et al., 2013).

In the research, an industrial building composed of steel frame and claddings was studied, and five DSs (see Table 21) were defined to develop fragility functions. A probabilistic simulation was conducted, and several material properties and wind parameters were considered as random variables under specific probability distributions. Then, the Monte Carlo simulation was performed to evaluate damage probabilities according to wind speeds and DSs, and fragility functions for building (enveloped), wall panel, roof panel, and window/door were obtained. Figure 78 shows typhoon fragility functions for each component; wall panel governs the fragility of the industrial building in this case.

4.4 FLOOD FRAGILITY

4.4.1 OVERVIEW

Damage probabilities for buildings due to flood (i.e., flood fragility function) largely depend on building location, topographical features, local environment, and ground altitude.

Thus, a typical estimation of fragility function according to building types and damage levels might not be suitable for flood hazard. No previous research for the flood fragility function on buildings in Yangon or Myanmar has been undertaken. However, some studies have identified the threshold of building collapse or collapse probability according to inundation depth as follows.

4.4.2 FEDERAL EMERGENCY MANAGEMENT AGENCY

FEMA Hazus refers to building collapse curves according to flood depth and overbank velocity (i.e., flood velocity(FEMA, 2013c).

This was analyzed by the Portland District of the United States Army Corps of Engineers, with curves that show collapse potential (i.e., collapse or no collapse, 100 percent or 0 percent) for three building types - wood frame, masonry or concrete bearing wall, and steel frame structures - as given in Figure 79. Highlighted in this figure, the collapse potentials are estimated for three different building heights, one-story, two-stories, and three-stories - buildings higher than four stories are assumed not to collapse due to flood. It is assumed that buildings designed with four or more stories possess sufficient resistance for loads due to flood inundation and velocity. Based on these collapse curves, wood construction is the most vulnerable to flooding, while masonry or concrete building is the most robust.

TABLE 21. DS definitions for an industrial building (Ham et al., 2009; Lee et al., 2013)

DS	DAMAGE DESCRIPTIONS	ENTRY/OVERHEAD DOOR FAILURE	ROOF PANEL PULLOUT FAILURE	WALL PANEL PULLOVER FAILURE
0	No damage	No	No	No
1	Minor damage	One door	One panel	One panel
2	Moderate damage	> 10%	> 10%	> 10%
3	Severe damage	> 20%	> 20%	> 20%
4	Destruction	> 33%	> 33%	> 33%

4.4.3 OTHER REFERENCES

A flood safety analysis for non-engineered masonry structures made of cement bricks in Africa analyzed flood fragility functions according to flood height Jalayer et al. (2016). The approach is based on a reliability analysis, with consideration of several uncertainties related to demand and capacity. More specifically, the structural performance is measured by the demand-to-capacity ratio for the weakest wall or critical component - within the structure, that is subjected to a combination of hydrostatic, hydrodynamic, and accidental debris impact loads.

An incremental flood height analysis is used to monitor the structural performance with material uncertainties as a function of increasing water height considering uncertainty. Figure 80 shows the case study model of a non-engineered masonry building in Africa. The research also conducted several case studies by differentiating structural resistance through the application of various flood mitigation strategies to compare with the original fragility function. Based on the many fragility functions in Figure 80, the strategy to increase platform height seems to be the most effective to avoid flood damage for this type of structure in Africa because its median value is about 50 percent higher than the original one.

FIGURE 78. **Typhoon fragility curves of an industrial building (Ham et al., 2009; Lee et al., 2013)**

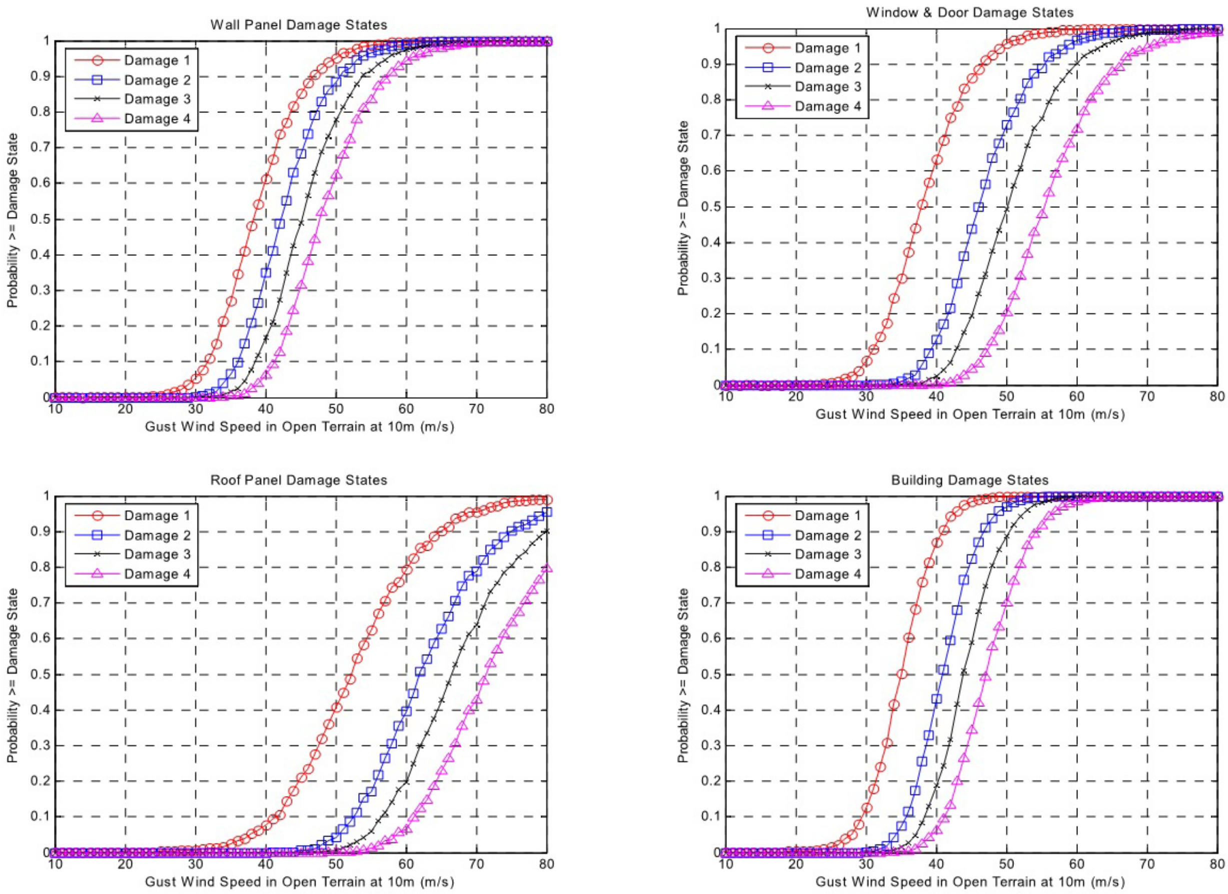
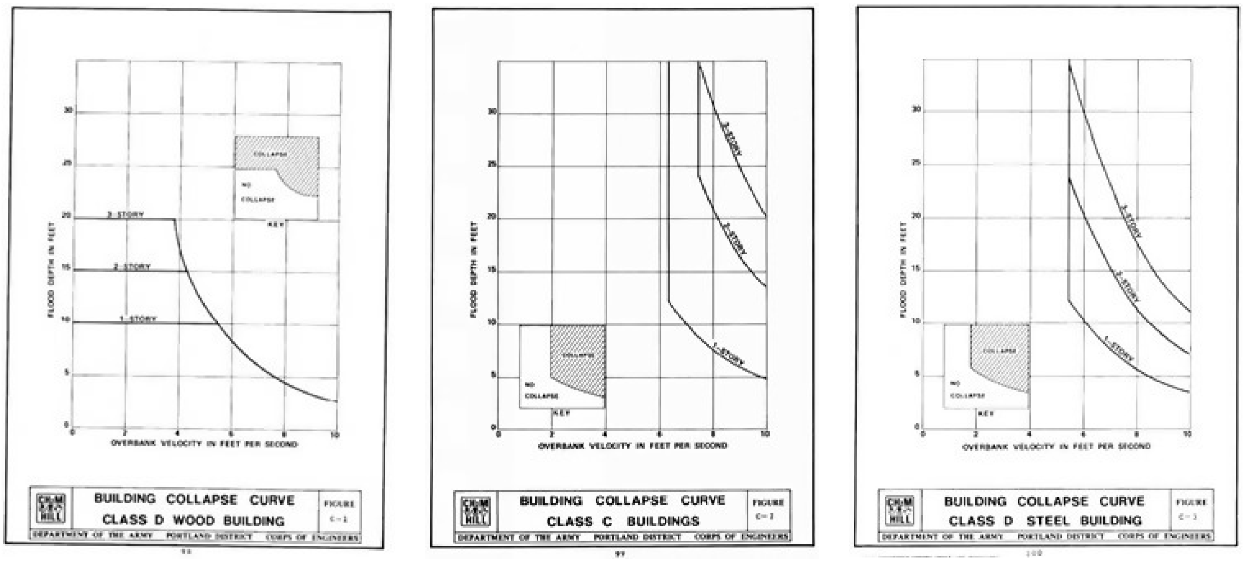


FIGURE 79. **Building flood collapse curve for various building types (FEMA, 2013c)**

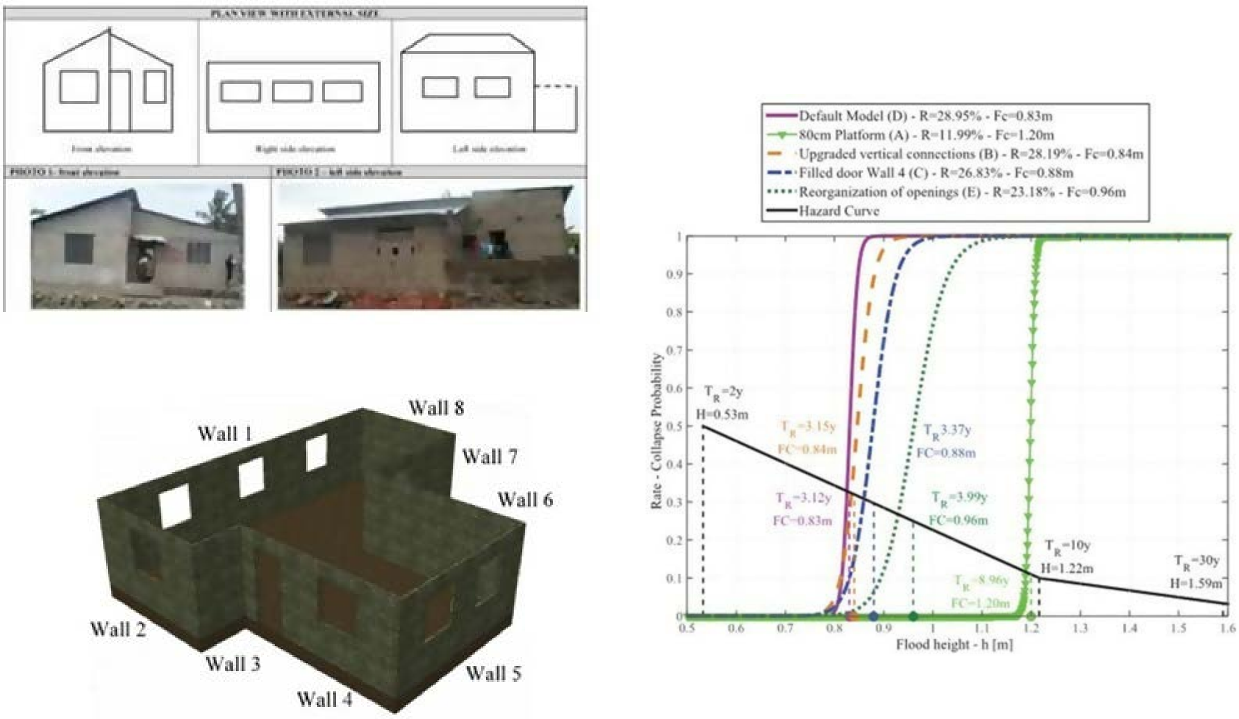


Wood

Masonry/concrete

Steelzzz

FIGURE 80. **Flood model for non-engineered masonry structures in Africa (Jalayer et al., 2016)**

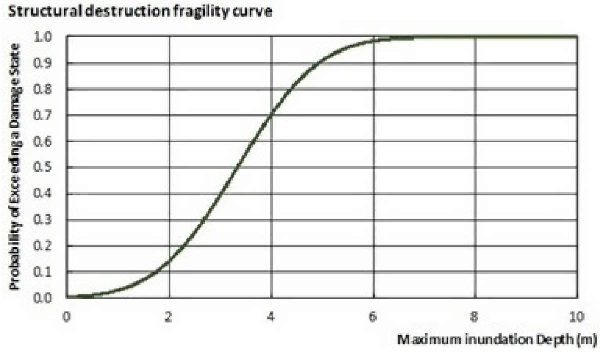


Structural model

Fragility functions

FIGURE 81. .Flood assessment in Banda Aceh city, Indonesia (Koshimura et al., 2009)

Building damage inspection results



Fragility functions

A fragility function for tsunami inundation depth was developed through an empirical approach using damage data from the tsunami caused by the 2004 Indian Ocean earthquake (Koshimura et al., 2009). Since the fragility functions of both floods and tsunamis are based on inundation depth, this tsunami fragility research seems to be a good reference for Myanmar, even though the flood damage scenario could be slightly different from tsunami damage. The research utilizes several satellite images and field surveys to identify the damage status of buildings in Banda Aceh, Indonesia, due to the tsunami (see Figure 81). In addition, the tsunami inundation depth at the target area was investigated and combined with the identified building damage. Based on these analyses, a fragility function was empirically developed (see Figure 81). It considers only two DSs, namely destruction or non-destruction, which is similar to the flood collapse curve/fragility function introduced in the former part of this section.

4.5 FIRE FRAGILITY

As discussed in section 2.5.4, fire in the aftermath of an earthquake is a major safety concern.

Using the Fire Following Earthquake model, FEMA (2003a) discusses the three phases of fire - ignition, spread, and suppression - to estimate:

- Number of ignitions
- Burned area
- Population exposed to the fire
- Buildings lost to the fire

Based on ignition data from past earthquakes in California, and using regression analysis, FEMA (2003a) developed an empirical relationship between the number of ignitions per km2 and the earthquake PGA (see Figure 82). Assuming these data can be applied to Yangon, an earthquake with PGA of 0.4 g could result in approximately one ignition per km2.

Hamada (1975) has developed a model for the spread of urban fire in Japan. The fire spread model accounts for the direction and velocity of the wind (see Figure 83). The general equation form depends on wind speed and direction. However, it is unlikely for an earthquake (and the resulting fire) to occur simultaneously with strong winds. Thus, in this section, wind velocity is assumed as zero, and the simplified equation is developed.

The general equation for calculating the spread of fire in urban areas can be written as Eq, 1:

$$N_t = 1.5\frac{\delta}{a^2}K_s K(a, d, f_b)t$$

Where:

- Nt is the number of fully burned structures
- t is time in minutes
- Ks is the width of fire flank in m
- a is the average plan dimension of the building
- d is average building separation in m
- fb is the fire resistance of the building
- d denotes the ratio of all buildings in a track, divided by the track area

For downtown Yangon, many of the buildings are constructed adjacent to one another (small d), and due to congested construction, most of the block tracks are nearly completely built (high d). For existing buildings, the dimension a is approximately 20–30 m. These values cannot be easily changed. The only parameters that can slow the spread of fire and are changeable are the building's fire-resistant characteristics and the number of such buildings in the wider pool of all the buildings. Figure 84 presents an example of the number of burned buildings, ranging from those with high fire resistance to low fire resistance after an earthquake fire event. As seen, there is substantial improvement when buildings are provided with fire resistance.

FIGURE 82. **Relation between number of ignitions and PGA (FEMA, 2003a)**

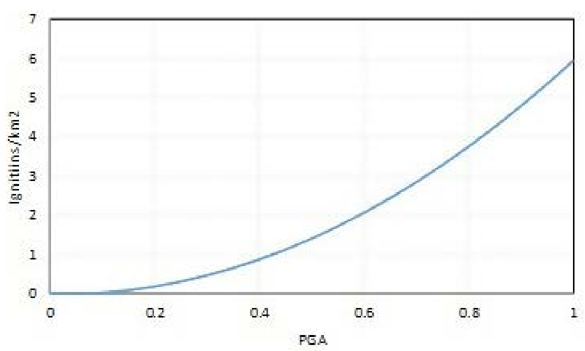
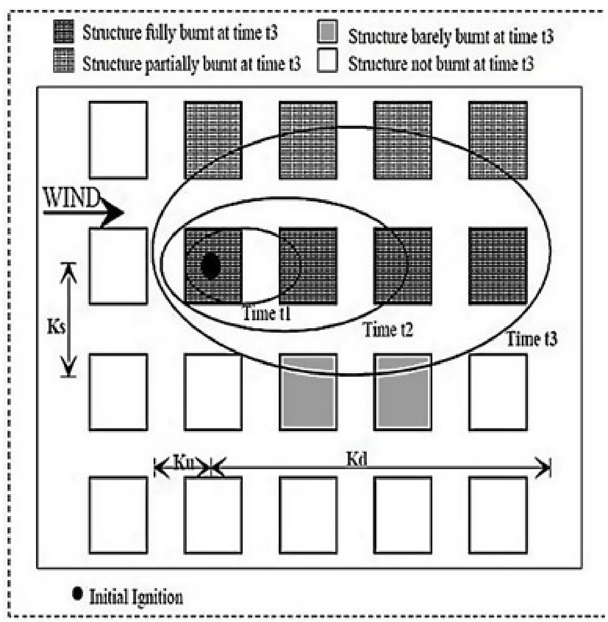


FIGURE 83. **Parameters contributing to the spread of fire (Hamada, 1975)**



The discussion below deals with the spread of fire without any suppression. Suppression is defined as the time to extinguish the fire and consists of the following (FEMA, 2003a):

- For occupied buildings, it takes 0 to 5 minutes to randomly discover the fire.
- After an earthquake, it takes 1 to 5 minutes to report the fire via cell or regular phone.
- After an earthquake, the arrival time for firefighters is longer due to road damage, debris, people on the street, traffic, and other factors; typical arrival time is 2–12 minutes.
- Control time depends on the status of fire when firefighters arrive.

The fire suppression effectiveness rate depends on the number of trucks and available water flow. The rate of spread of fire is modified as shown in Eq,2:

2. Spread rate $_{\text{suppressed}}$ = spread rate $_{\text{not suppressed}}$ (1-suppression effectiveness)

4.6 DISCUSSION

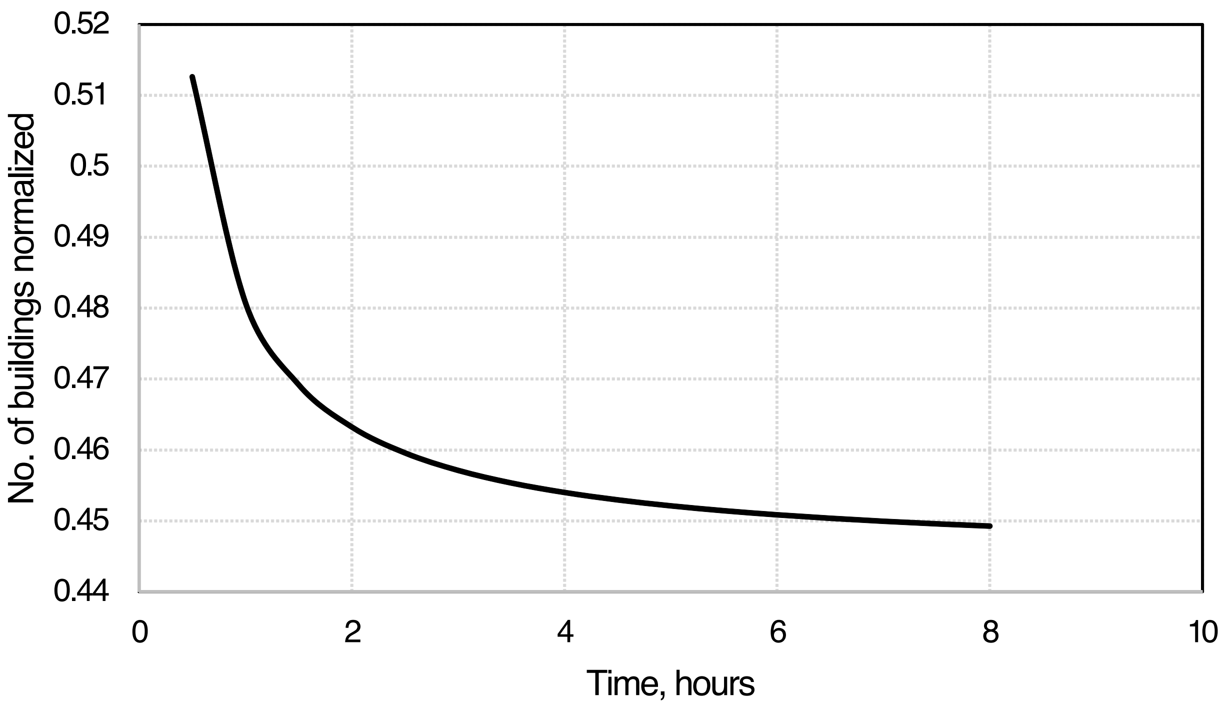
Yangon is a congested urban area with a number of building types susceptible to damage from natural hazards.

4.6.1 EARTHQUAKE FRAGILITY

A large number of existing buildings in the city were constructed using unreinforced masonry bearing walls - one of the building types most vulnerable to earthquakes.

Many newer buildings use RC construction. When properly designed, detailed, and constructed, RC buildings perform well in earthquakes. However, field surveys and interviews with YCDC have shown that the concrete used in construction presents low strength and stiffness. In addition, the reinforcement is undersized, exposed to corrosion, and has large variation in material property. Finally, the pool of qualified construction workers in the city is limited, partially due to low wages. As a result, even the newer RC buildings in the city are susceptible to earthquake damage. BN construction is also present in Yangon. This building type performed poorly during the 2012 earthquake in Myanmar.

FIGURE 84. Examples of fire spread scenarios



4.6.2 CYCLONE FRAGILITY

Fragility functions for cyclones, hurricanes, and typhoons have been developed all over the world.

Most of these adopt wind speed as the hazard index for fragility function and were developed by applying both statistical and analytical methodologies. Historical records of cyclone wind speeds and damage in Myanmar, and more specifically Yangon, are useful for the development of cyclone fragility functions according to building types. Generating these functions is a critical task: as discussed in the cyclone hazard chapter, a cyclone monitoring system has been operating in Myanmar, so the records monitored at each station could be utilized for this purpose. Also, to develop the fragility functions, it is necessary to conduct an analysis to identify wind force resistance for comparison to the various wind forces due to cyclones. Since a fragility function can identify the DS probabilities (i.e., probability function), it is relatively straightforward to estimate the building damage level caused by a specific intensity of the cyclone. Thus, it is important to develop cyclone fragility functions for proceeding and improving cyclone disaster preparation in Yangon and Myanmar as a whole.

4.6.3 FLOOD FRAGILITY

Fragility functions (e.g., the median value of fragility) are different depending on the local environment and structural types of buildings,

This was observed in the past research projects regarding flood and tsunami fragility functions according to inundation depth discussed in the previous section. Developing flood fragility functions for the environment and building types in Yangon and Myanmar is thus fundamental to improve flood disaster research. Since a fragility function can identify the damage status probabilities of a building (i.e., probability function), it is useful to estimate building damage level due to a specific intensity of flood. Therefore, a flood fragility function, in addition to a flood vulnerability curve of buildings which identifies damage volume or loss amount, needs to be developed and utilized for both Myanmar and Yangon.

4.6.4 FIRE FRAGILITY

Fire after an earthquake has been a major concern in the past events in Yangon.

If the city of Yangon experienced a designlevel earthquake, it is likely that there would be ensuing fires. Given the congested housing, the small separation between buildings, and lack of yards, fire could spread rapidly. The spread of fire can be slowed significantly by ensuring that the buildings are fire-resistant. Furthermore, it is important to ensure that there are sufficient fire engines and access to water is in place to accelerate fire suppression and reduce the chance of the fire spreading.

5. Vulnerability Assessment Methodologies and Screening

5.1 OVERVIEW

A probabilistic or deterministic Vulnerability Assessment (VA) is conducted to assess the consequences of natural hazards before they occur and to plan for such occurrences.

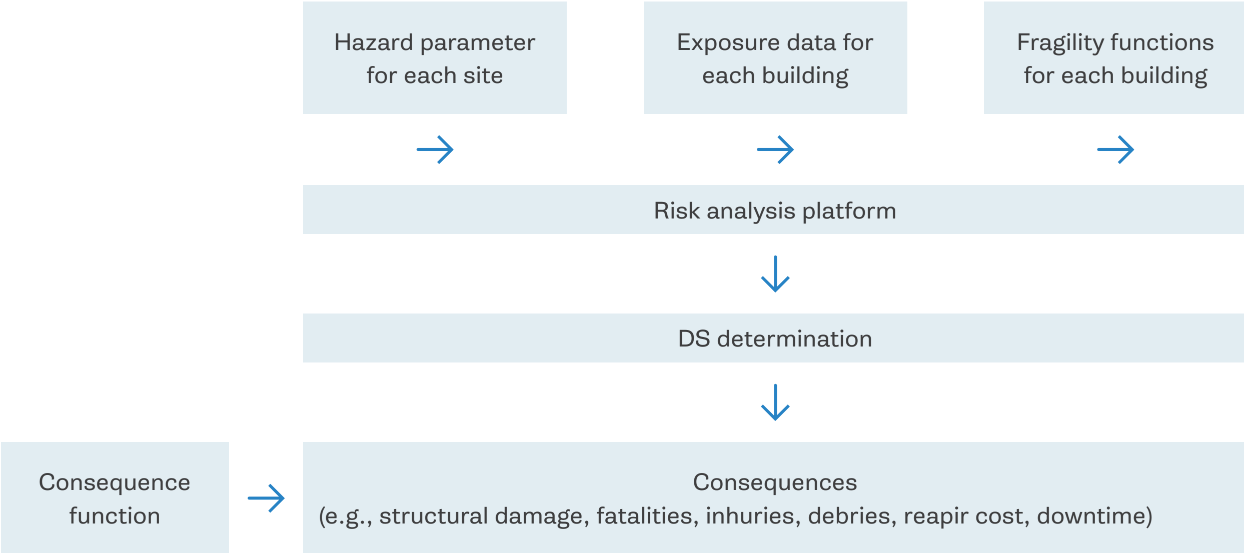
VA can either be rapid (RVA) or detailed. Typically, when a subject study area covers a large footprint (such as a city or a township) or a specific class of buildings (such as all public schools or heritage buildings), RVA is conducted to identify the most vulnerable infrastructure and plan mitigation. On the other hand, when the study pool is limited (such as in the case of individual buildings or a portfolio of buildings), detailed visual assessment can be conducted to collect a more complete dataset to address specific buildings. An example of the former includes the work of Win et al. (2018) in which the authors assessed the seismic vulnerability of buildings for four townships in Yangon. An example of the latter includes the current project by Mon et al. (2016) in which the authors perform a seismic risk assessment for specific buildings in Myanmar and the Philippines.

VA, or risk analysis, is conducted to estimate the consequence metric associated with a given risk. The inputs to the process include (i) hazard parameter; (ii) building exposure data, including the number of occupants and footprint; (iii) building fragility function; and (iv) functions for the consequences of interest. The flowchart used in this project to compute the fatality rate is presented in Figure 85.

The computation is conducted for each building individually. Next, the data can be statistically processed to obtain aggregate results by, for example:

- Aggregating structural damage, fatalities, and debris to obtain the sum for a city and township. This data can then be used as part of DRM planning and preparation and allocation of resources.
- Performing a cost-benefit analysis. A derived consequence parameter, such as the number of lives saved or the repair cost per m2, can be selected. The VA data can then be sorted to prioritize the most critical structures and allow for phased improvement. The data can then be used to allocate finite financial resources more optimally.

FIGURE 85. Flowchart used for natural hazard VA



5.2 EARTHQUAKE VULNERABILITY ASSESSMENT

5.2.1 INTRODUCTION

Earthquake VA could be performed both for a large number of buildings as well as for a handful of structures.

For the former, a quick and less detailed approach is needed, whereas, for the latter, a more detailed method is warranted. Both approaches are described in this section.

5.2.2 ASCE 41

When assessing individual buildings, a more detailed approach is warranted.

The objectives of such an assessment are to identify the weak spots and vulnerable components that can be damaged and compromise structural integrity in the event of an earthquake. This approach has been used by engineering firms in Yangon, although findings are not publicly available because the buildings are privately owned (BECA, 2019).

ASCE 41-17 (ASCE, 2018) has been developed for such approaches. The document and its earlier editions were developed for use in the USA and have been widely adopted worldwide.

The standard includes three tiers (levels) of assessment. The assessment starts with Tier 1 evaluation. This is the most conservative tier; if deficiencies are identified, the user can either address them through reinforcement or continue to other tiers to see if a more detailed analysis would show that the structure is safe. The basic procedure for Tier 1 evaluation is as follows:

- Visit the building and collect pertinent information. Review construction drawings. Identify site seismicity.
- Complete structural checklist with options of compliance (C), non-compliance (NC), not available (N/A), or unknown (U) for each item.
- Summarize deficiencies and identify further action.

As an example, Table 22 presents a sample Tier 1 checklist for a RC moment frame building (Type C1), a common construction type for new buildings in Yangon.[19]

- The primary objective of the checklist for this and other building types is to ensure the following:
- There is a complete load path to transfer the inertial forces from the building floors to vertical elements and to the foundation.
- There is redundancy and, in case of failures in one frame, the building is still capable of carrying the gravity loading and does not collapse.
- Critical elements such as columns and joints are capacity-protected, and yielding occurs in designed and predetermined elements.
- Proper seismic detailing is used to prevent brittle and sudden modes of failure and instead allow for dissipation of earthquake input energy through a ductile mechanism.

19. Table 22 shows selected items for the structural checklist based on collapse prevention for high seismicity. For a more complete description, please refer to ASCE 41 Tier 1 checklist for C1 buildings.

TABLE 22. Sample Tier 1 checklist items for RC moment frame building (ASCE, 2018)

ITEM	EVALUATION STATEMENT	CHECK ONE			
		C	NC	N/A	U
Redundancy	The number of lines of moment frames in each principal direction is greater than or equal to two.				
Walls	All concrete and masonry infill walls placed in moment frames are isolated from structural elements.				
Column axial load	The axial stress caused by gravity loads in columns subjected to overturning forces because seismic demands is less than 0.20f c.				
Foundation connection	All concrete columns are doweled into the foundation with a minimum of four bars.				
Column shear check	The shear stress in the concrete columns, calculated using the Quick Check procedure, s less than 0.69 MPa.				
Beams	The seismic-force-resisting system is not a frame consisting of columns and a flat slab or plate without beams.				
Captive column	There are no columns at a level with height to depth ratios less than 50% of the nominal height to depth ratio of the typical columns at that level.				
Flexure governs	The shear capacity of frame members is able to develop the moment capacity at the ends of the members.				

ITEM	EVALUATION STATEMENT	CHECK ONE			
		C	NC	N/A	U
Strong column	The sum of the moment capacity of the columns is 20% greater than that of the beams at frame joints.				
Beam reinforcement	At least two longitudinal top and two longitudinal bottom bars extend continuously throughout the length of each frame beam. At least 25% of the longitudinal bars provided at the joints for either positive or negative moment are continuous throughout the length of the members.				
Column reinforcement splice	All column-bar lap splice lengths are greater than 35db and are enclosed by ties				
Beam reinforcement splice	The lap splices or mechanical couplers for longitudinal beam reinforcing are not located within lb/4 of the joints.				
Column tie spacing	Frame columns have ties spaced at or less than d/4 throughout their length and at or less than 8 db at the joints.				
Beam stirrups	All beams have stirrups spaced at or less than d/2 throughout their length. At potential plastic hinge locations, stirrups are spaced at or less than the minimum of 8 db or d/4.				
Joints	Beam-column joints have ties spaced at or less than 8 db.				
Diaphragms	The diaphragms are not composed of split-level floors and do not have expansion joints.				
Uplift	Pile caps have top reinforcement, and piles are anchored to the pile caps.				

5.2.3 FEMA P-154 RAPID VISUAL SCREENING

When assessing a large number of buildings for vulnerability to natural hazards, it is critical to have a simple form that allows for consistency of collected data between various surveyors and can be completed rapidly. [20]

The main purpose of such a survey is to identify the most vulnerable buildings so that stakeholders can undertake countermeasures, such as strengthening the structure, prior to the occurrence of a natural hazard.

FEMA P-154 (FEMA, 2015) was created for such a purpose. Developed in response to cases of seismic hazard for the USA, it has been adopted worldwide. The handbook provides two levels of screening: Level 1 (basic), and Level 2 (a more detailed professional screening option, that can be undertaken as one of the recommendations of a Level 1 screening). A typical screening form for a region of moderately high seismicity is presented in Figure 86. The surveyors will collect the following sets of data:

- General building information, such as GPS coordinates and name.
- Building geometry, including number of stories, footprint, and year built.
- Type of soil and building irregularities.[21]
- Building framing.
- Recommendations for further action.

It is intended that the form be completed by surveyors after a brief classroom and field training and without the need to enter the building. Based on the building framing, construction age, soil type, and irregularities, a final score is then assigned to each completed form, indicating the level of its vulnerability to earthquakes.

5.2.4 UN-HABITAT

UN-Habitat (2016b) developed a guideline for the seismic rapid visual screening (RVS) of buildings in Myanmar.

This document was prepared based on FEMA P-154 and modified for application specifically in Myanmar. The key features of the guideline include:

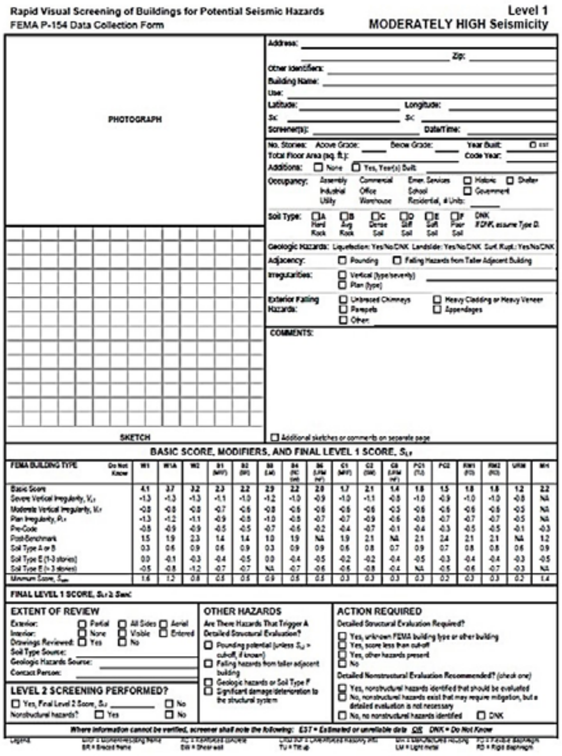
- Five seismic zones, from low to very high, are identified. Yangon falls in the moderately high category (S_S = 0.77 g and S_1 = 0.31 g). Twelve occupancy categories and 19 building types are defined. The occupancy categories are similar to FEMA P-154 with the addition of two types of BN framing, with BN1 and BN2 designating good and poorly constructed buildings, respectively. Building irregularities are also documented.
- The scoring system is derived from FEMA P-154 with similar numerical values.

An example of RVS form for a region of moderate seismicity such as Yangon is presented in Figure 87. UN-Habitat has conducted training on the use of RVS and is currently updating the training guidelines. The RVSs conducted in downtown townships were in part based on the work conducted by UN-Habitat.

20. At sites where more than one building is present, such as a school campus, a separate form for each individual building needs to be completed.

21. Past earthquakes have shossssssssssssswn that buildings with irregular configuration perform significantly worse than regular buildings.

FIGURE 86. Sample earthquake Level 1 RVS form (FEMA, 2015)



Rapid Visual Screening of Buildings for Potential Seismic Hazards
FEMA P-154 Data Collection Form

Level 1
MODERATELY HIGH Seismicity

PHOTOGRAPH

SKETCH

BASIC SCORE, MODIFIERS, AND FINAL LEVEL 1 SCORE, S_{L1}

FINAL LEVEL 1 SCORE, $S_{L1} \geq S_{MIN}$

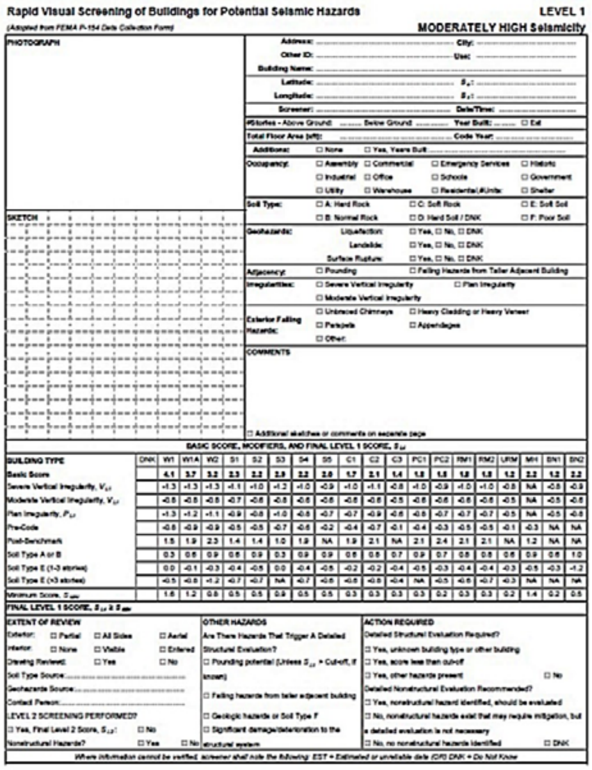
EXTENT OF REVIEW

OTHER HAZARDS

ACTION REQUIRED

LEVEL 2 SCREENING PERFORMED?

FIGURE 87. Sample earthquake Level 1 RVS form (UN-Habitat, 2016b)



Rapid Visual Screening of Buildings for Potential Seismic Hazards
(Adapted from FEMA P-154 Data Collection Form)

LEVEL 1
MODERATELY HIGH Seismicity

PHOTOGRAPH

SKETCH

BASIC SCORE, MODIFIERS, AND FINAL LEVEL 1 SCORE, S_{L1}

EXTENT OF REVIEW

OTHER HAZARDS

ACTION REQUIRED

5.2.5 KYAUKTADA TOWNSHIP RAPID VISUAL SCREENING

A detailed RVS was conducted of Kyauktada Township, which is located at the center of downtown Yangon and includes nine wards.

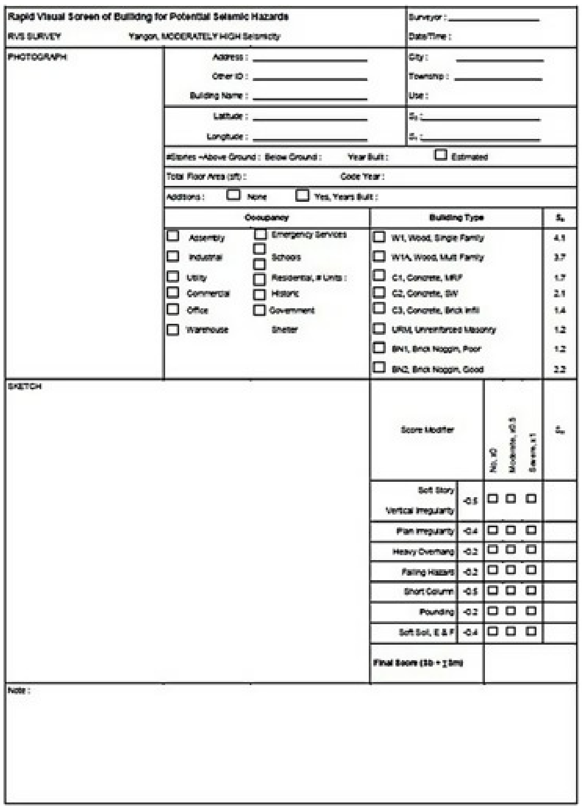
This township has an approximate area of 0.6 km^2 and a population of around 30,000 residents. The township houses many important buildings, including the Sule Pagoda, several heritage buildings including 39 landmarks, the city hall, and a number of embassies. The borders of the township are presented in Figure 88.

Win (2017) conducted the RVS of the township using the FEMA P-154 methodology (FEMA, 2015). Figure 89 presents a sample survey form based on FEMA P-154 and adapted to Yangon construction. In total, 818 individual buildings were surveyed. The key properties of the surveyed buildings were as follows, as adapted from Win (2017):

- Approximately one-third of all buildings were three-story structures, and 21 percent were four-story buildings. Overall, close to 47 percent of the buildings were low-rise (one to three stories), 38 percent were mid-rise (four to seven stories), and 5 percent were high-rise (eight and more stories) (see Figure 90).
- The survey data were supplemented with additional information available from the Government and other sources. For the pool of 1,130 buildings, the breakdown according to occupancy type is shown in Figure 91. Note that approximately 60 percent of the buildings are residential units, while 30 percent are commercial buildings. Government buildings account for 4 percent of the total.

FIGURE 88. Kyauktada Township (YCDC 2019).

FIGURE 89. ssRVS form (Win, 2017).



Rapid Visual Screen of Building for Potential Seismic Hazards
RVS SURVEY Yangon, MODERATELY HIGH Seismicity
Surveyor :
Date/Time :

PHOTOGRAPH
Address :
Other ID :
Building Name :
City :
Township :
Use :
Latitude :
Longitude :
S_S :
S_1 :
#Stories –Above Ground : Below Ground : Year Built : ☐ Estimated
Total Floor Area (sft) : Code Year :
Additions : ☐ None ☐ Yes, Years Built :

Occupancy		Building Type	S_L
☐ Assembly	☐ Emergency Services	☐ W1, Wood, Single Family	4.1
☐ Industrial	☐ ☐ Schools	☐ W1A, Wood, Mult Family	3.7
☐ Utility	☐ Residential, # Units :	☐ C1, Concrete, MRF	1.7
☐ Commercial	☐ Historic	☐ C2, Concrete, SW	2.1
☐ Office	☐ Government	☐ C3, Concrete, Brick infil	1.4
☐ Warehouse	Shelter	☐ URM, Unreinforced Masonry	1.2
		☐ BN1, Brick Noggin, Poor	1.2
		☐ BN2, Brick Noggin, Good	2.2

SKETCH

Score Modifier		No, x0	Moderate, x0.5	Severe, x1	S_M
Soft Story / Vertical Irregularity	-0.5	☐	☐	☐	
Plan Irregularity	-0.4	☐	☐	☐	
Heavy Overhang	-0.2	☐	☐	☐	
Falling Hazard	-0.2	☐	☐	☐	
Short Column	-0.5	☐	☐	☐	
Pounding	-0.2	☐	☐	☐	
Soft Soil, E & F	-0.4	☐	☐	☐	
Final Score (Sb + ∑Sm)					

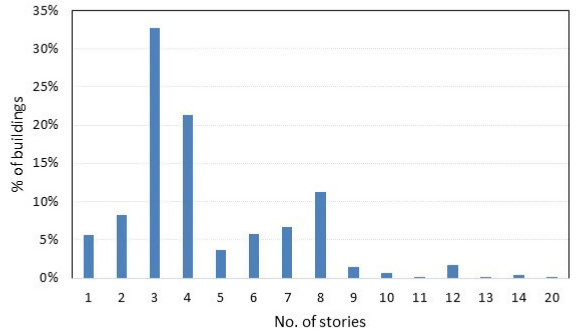
Note :

- For 698 buildings, the construction date was available. As shown in Figure 91, over 50 percent of the buildings were constructed before 1980, and approximately 90 percent were built before 2003. Over 40 percent of buildings used URM construction. RC frame buildings (C1: RC moment frame; C2: RC shear wall; C3: RC moment frame with infill masonry) account for approximately 55 percent of all buildings. There is a small percentage of BN buildings and only a few steel framed buildings.
- The population distribution for the nine wards in the township is presented in Figure 90. As shown, the distribution is higher in some of the wards.

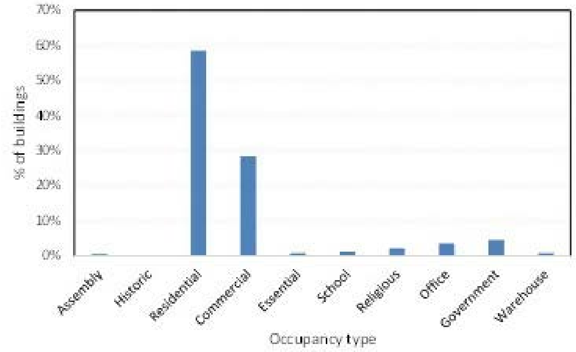
Next, using FEMA P-154 Level 1 methodology, Win (2017) conducted VAs for the surveyed buildings. FEMA P-154 (FEMA, 2015) considers seismicity of region, building type, irregularities, construction period, and soil type to compute a "final score" for each surveyed building. For each building, the basic score was modified to account for the presence of various irregularities. Based on the final score, the building was assigned to one of three categories depending on implied seismic vulnerability. As shown in Figure 91, nearly 65 percent of buildings were classified as low-risk, and 35 percent as moderate to high risk. Figure 91 presents the average calculated score depending on the building framing. RC moment frames and shear wall buildings scored the highest.

The spatial distribution of the buildings and the vulnerability group assigned to individual buildings in the township is presented in Figure 92 (Win, 2018b).

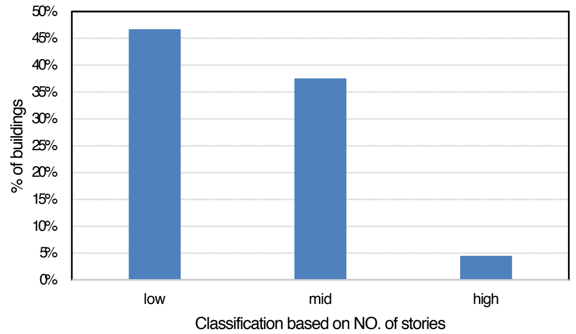
FIGURE 90. Composition of surveyed buildings (adapted from Win, 2017)



Based on number of stories

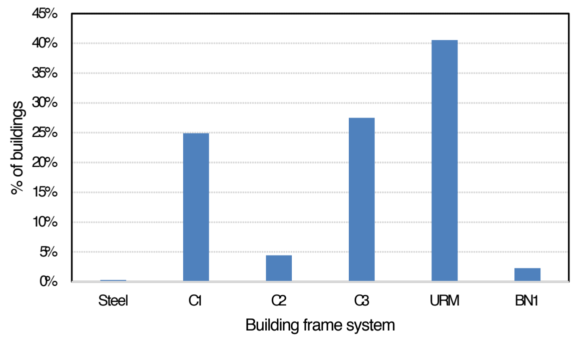


Based on occupancy type

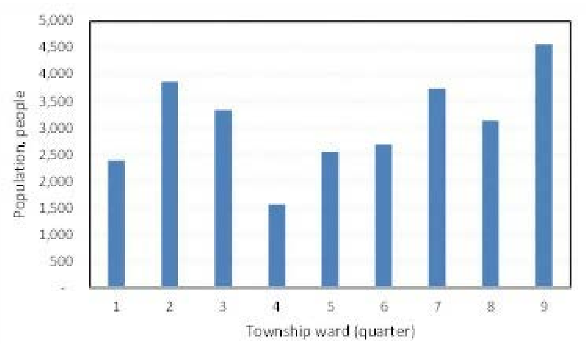


Based on the height classification

Based on construction period

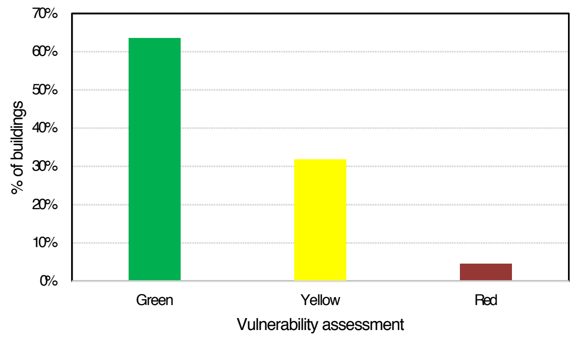


Based on the lateral system

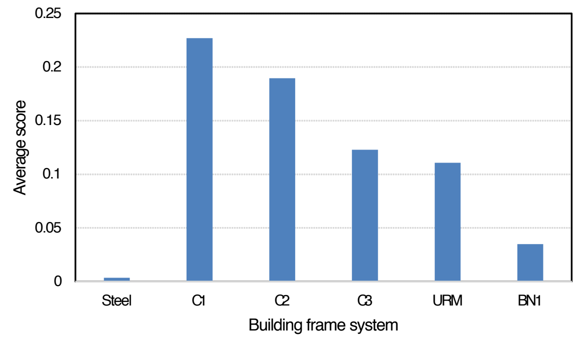


Population of township wards

FIGURE 91. VA of township buildings (Win, 2017)



Overall vulnerability



Building framing system

FIGURE 92. Map of township showing the assigned seismic vulnerability group (Win, 2018)

5.2.6 FOUR-TOWNSHIP RAPID VISUAL SCREENING

Win et al. (2018) and the Engineering Department (Buildings) (EDB, 2017) extended the RVS to four additional townships in downtown Yangon (see Figure 93).

As part of this program, an assessment of the buildings was conducted, and the buildings were assigned a vulnerability score. It is noted that the scoring approach was based on the physical damage of existing buildings, and was not directly related to the assessment.

The townships included:

- Pabedan Township located in downtown Yangon. The township has 11 wards and an approximate area of 0.8 km^2. With 40,000 residents, the township includes the famous Bogyoke Aung San Market and Theingyi Market.
- Latha Township located in downtown Yangon. The township has 10 wards and an approximate area of 0.8 km^2. With 30,000 residents, the township includes a number of landmarks and a portion of the Yangon Chinatown.
- Lanmawdaw Township located in downtown Yangon. The township has 12 wards and an approximate area of 1.4 km^2. With 34,000 residents, the township includes a number of landmarks and a portion of the Yangon Chinatown and houses the University of Medicine and Institute of Nursing.
- Pazuntaung Township, located in Southeastern Yangon. The township has 10 wards and an approximate area of 1.0 km2. With 31,000 residents, the township includes a number of landmarks and is connected to other townships via the 1.1-km cable-stayed Maha Bandula Bridge completed in 2001.

TABLE 23. Surveyed buildings per township and vulnerability results

TOWNSHIP	G	Y	R	TOTAL
Pabedan	595	381	21	**997**
Latha	516	359	57	**932**
Lanmawdaw	952	402	27	**1,381**
Pazuntaung	1056	78	1	**1,135**
Total	**3,119**	**1,220**	**106**	**4,445**
%	70%	27%	2%	**100%**

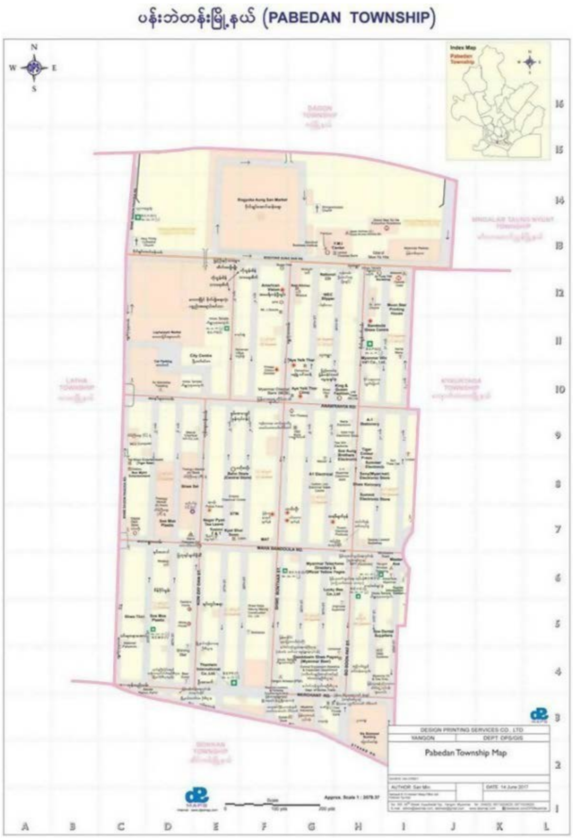
The surveys were sponsored in part by Plan International and Kyoto University and included 25 percent of all buildings in the Pabedan Township and all buildings in ward 2 of Pazuntaung Township:

- In Pabedan Township, there are a few RC buildings with eight or more stories, but the majority are four- or five-story masonry buildings. Most structures are residential.
- In Pazuntaung Township, the majority of buildings are residential and eight- to 10-story RC structures. There are also a number of masonry, wood, and BN low-rise structures.

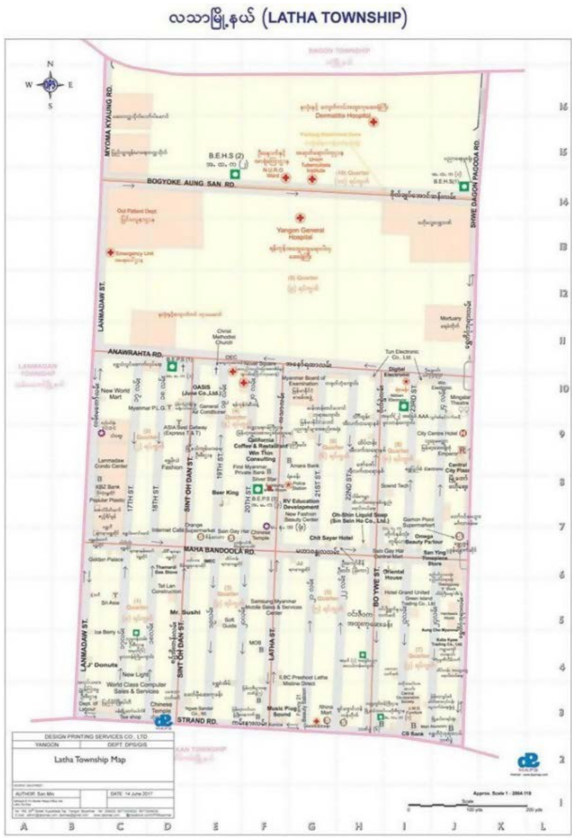
As shown in Table 23, close to 4,500 buildings were assessed in the four townships. Approximately 70 percent of buildings were found to have low vulnerability, while nearly 30 percent require additional investigation on strengthening. Figure 94 presents the distribution of vulnerability across the townships.

The spatial distribution of the buildings and the vulnerability group assigned to individual buildings in the townships is presented in Figure 95 (Saw, 2018).

FIGURE 93. Maps of the four townships (YCDC 2019)



Pabedan Township



Latha Township

Lanmawdaw Township

Pazuntaung Township

FIGURE 94. Distribution of vulnerability grouping for the townships (EDB, 2017

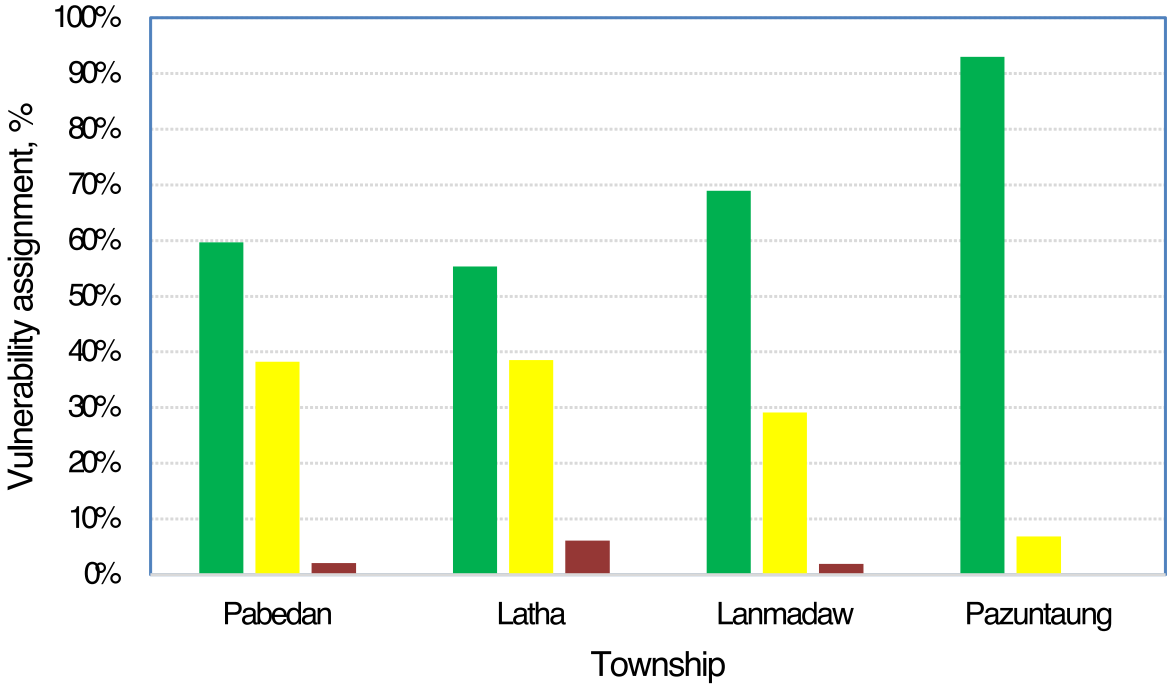


FIGURE 95. Maps of townships showing the assigned seismic vulnerability group (Saw, 2018)

Pabedan Township (partial)

Pazuntaung Township

5.2.7 SCHOOL BUILDINGS IN HLAING THAYER TOWNSHIP

School buildings and facilities in the Hlaing Thayer Township were assessed as part of a program sponsored by the Myanmar Red Cross Society (MRCS).

Hlaing Thayer Township is located in western Yangon and was developed as a satellite town in the 1980s. The township has 20 wards and nine village tracts and is one of the largest and most populous townships in the country. This township has an approximate area of 67 km^2, a population of 700,000 residents, and a large number of light industries including an industrial park. There are a number of educational sites in the township, including 32 public primary schools, 18 public middle schools, and eight public high schools, as well as the west campus of YTU.

Figure 96 presents the map of the township. At the time of writing, data from RVS results of the educational facilities were not available.

5.2.8 TARMWE TOWNSHIP

Kyoto University undertook a RVS of the Tarmwe Township, located in east-central Yangon. The surveys were sponsored in part by Kyoto University and included all buildings in the Byainekwetthit ward.

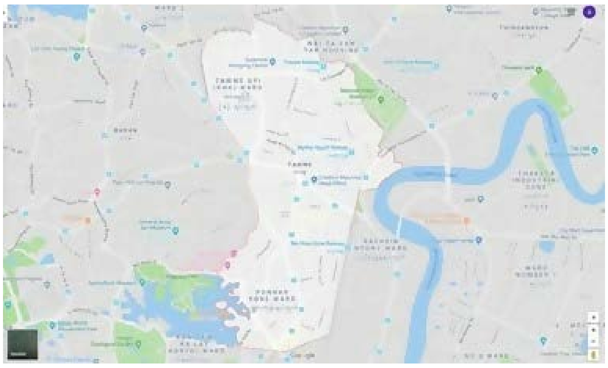
The township has 20 wards, an approximate area of 44 km^2, a population of 140,000 residents, and includes over 60 monasteries, a large number of schools, several markets, and two hospitals. Figure 97 presents the map of the township.

In the township, the majority of buildings are five- to seven-story RC buildings, and a smaller number of wood and BN buildings exist. In total, RC, BN, and wood framing represent 73 percent, 14 percent, and another 14 percent of all buildings, respectively (Grant for Global Sustainability (GGS), 2018). Most structures have either residential or commercial occupancy.

The spatial distribution of the buildings and the vulnerability group assigned to individual buildings in the townships is presented in Figure 97 (Saw, 2018). For the assessed buildings, the wood structures performed well, while the RC and BN structures had a lower score (MEC, 2018).

FIGURE 96. Map of the Hlaing Thayer Township

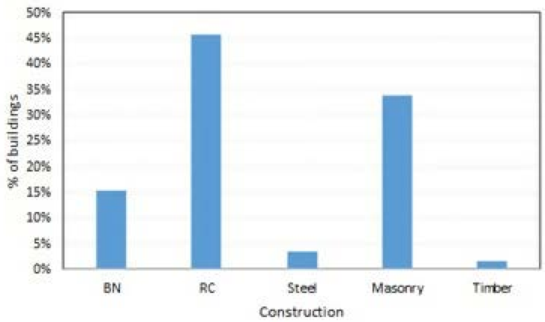
FIGURE 97. Township maps showing the assigned seismic vulnerability group (Saw, 2018)



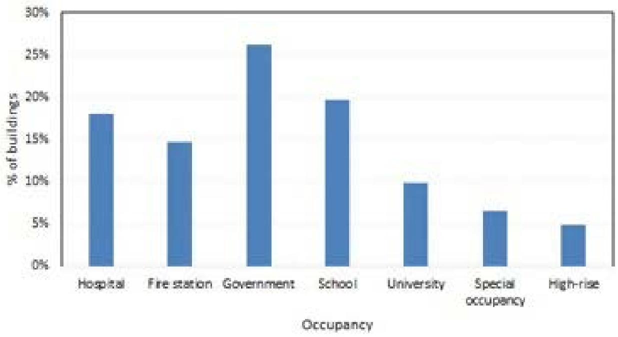
Township map

RVS results

FIGURE 98. Building distribution per construction type (Saw, 2018; YCDC, 2019)



Construction type



Occupancy type

FIGURE 99. Location of public facilities for RVS

5.2.9 ESSENTIAL PUBLIC FACILITIES

UN-Habitat sponsored RVS of 61 essential public buildings in Yangon.

The distribution of building construction types and occupancy is presented in Figure 98.

One facility was a hospital constructed in 1991 and comprising properly maintained RC buildings. Structurally, the hospital buildings were in better condition than the school buildings.

Figure 99 shows the distribution of selected facilities based on available geographic locations extracted from building names[22]. In the Figure, the locations of selected surveyed fire stations, schools, hospitals, government, and high-rise buildings are shown.

5.2.10 Analytical assessment of existing RC buildings

Kyaw et al. (2018) from YTU performed a seismic evaluation of existing RC buildings in Yangon.

The study focused on three RC buildings in Tarmway, Pazundaung, and Kyaukdadar townships—townships with high population density and poor soil conditions—using three-, six-, and eight-story buildings. Based on material testing, a concrete strength of 25 MPa was used in the analysis. Three performance levels were defined:

- I: Immediate occupancy at frequent earthquake
- I: Life safety at design (475-year) earthquake
- III: Collapse prevention at maximum (2475-year) earthquake

The findings are summarized in Table 24. The existing RC buildings cannot withstand earthquakes; in particular, they have a high probability of collapse during severe earthquakes and thus require strengthening.

TABLE 24. Probability of failure (not meeting performance) (Kyaw et al., 2018)

NUMBER OF STORIES	I	II	III
3	60%	23%	93%
6	34%	24%	92%
8	49%	26%	95%

5.3 CYCLONE VULNERABILITY

5.3.1 INTRODUCTION

A cyclone VA for a specific area or built environment is necessary to identify less robust areas and buildings that can be easily damaged; however, no detailed assessments have been performed in Myanmar to date.

Vulnerability maps and curves are particularly useful in assessing disaster vulnerability. A disaster vulnerability map is developed through hazard analysis, exposure model, fragility/consequence function, and disaster damage/loss estimation. The estimated vulnerabilities according to a certain resolution of spatial area of a target region are then projected onto a map. A vulnerability curve expressing damage ratio or fatality percentage according to a disaster intensity level is typically established for a building or component based on statistical records and field investigations of damage/loss due to past disasters. Through regression analysis or likelihood method, mathematical parameters of a vulnerability curve can be identified. A vulnerability map can be considered as a macroscopic VA, and a curve as a microscopic VA. In this section, some past studies for both items are discussed.

5.3.2 CYCLONE VULNERABLE AREA IN MYANMAR

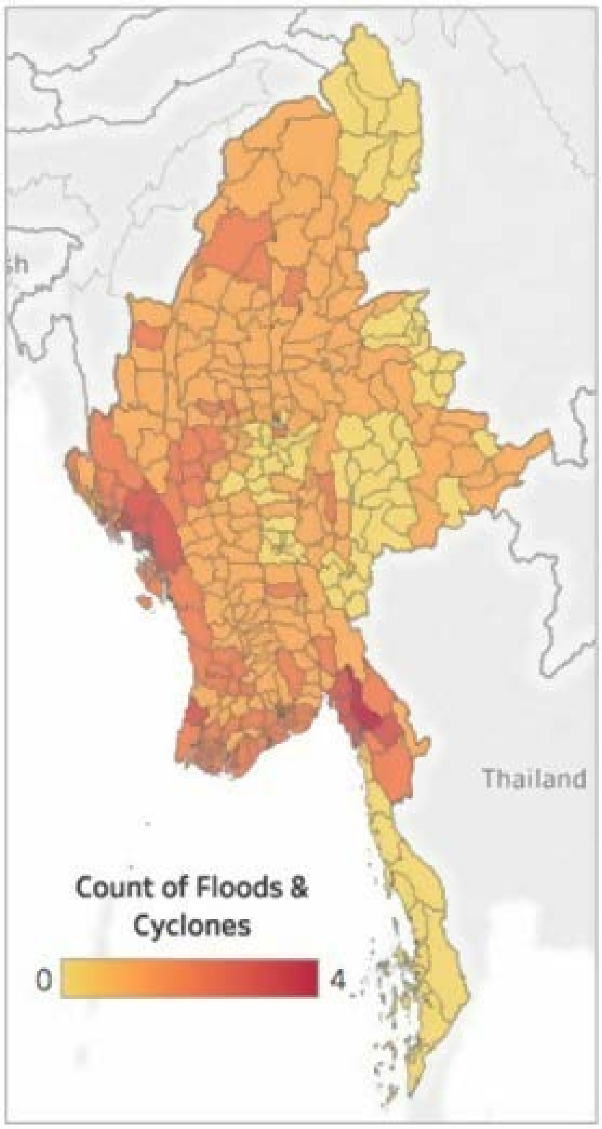
A report presented by DMH (DMH, 2018) determined that the coastal regions of southwestern Myanmar are susceptible to cyclones and tsunamis.

The map in Figure 100 was created using cyclone landfall data and tsunami records in Myanmar. A similar map presented, in Figure 101, can be found in a report by the Humanitarian Assistance and Resilience Programme Facility (HARP) and MIMU (HARP and MIMU, 2018). This map shows the areas affected by significant flooding and cyclones between 2008 and 2015. As with Figure 100, the coastal regions seem to be cyclone-prone areas. While these two Figures are not considered vulnerability maps because they do not show damage/loss due to cyclone, they show the areas most affected by cyclone and cyclone-induced flood Myanmar.

22. GPS coordinates for some facilities were not known.

FIGURE 100. Cyclone and tsunami-vulnerable area in Myanmar (DMH, 2018)

FIGURE 101. Frequency of floods and cyclones in Myanmar, 2008–2015 (HARP and MIMU, 2018)

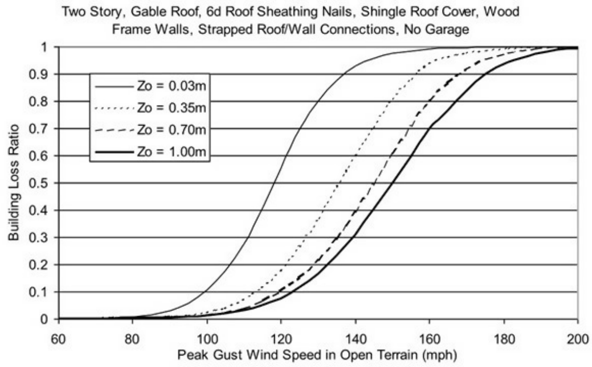


5.3.3 FEDERAL EMERGENCY MANAGEMENT AGENCY

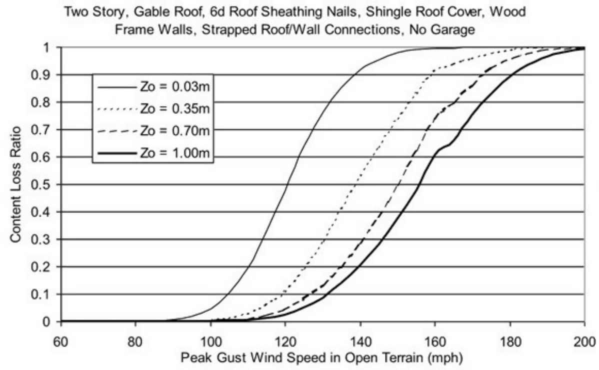
FEMA Hazus (FEMA, 2013b) developed several hurricane vulnerability curves (or loss functions) for various building types. The Hazus loss/damage estimation model first subdivides buildings into costing subassemblies and then estimates building interior and content loss in addition to building damage. A set of vulnerability curves is shown in Figure 102. These curves display residential building and content loss according to peak gust wind speed. The curves are estimated according to surface roughness (z0). It is evident that residential buildings with more open space are more vulnerable and susceptible to cyclone damage.

In addition to damage vulnerability curves, FEMA Hazus also generates vulnerability curves for estimating the number of displaced households due to a hurricane (see Figure 103). It is assumed that this displacement is due to the loss of habitability after the cyclone. Thus, a vulnerability curve can be developed not only for physical damage of buildings but also for secondary loss due to building damage, and it is useful for a comprehensive disaster VA.

FIGURE 102. Hurricane vulnerability curves for building and content (FEMA, 2013b)

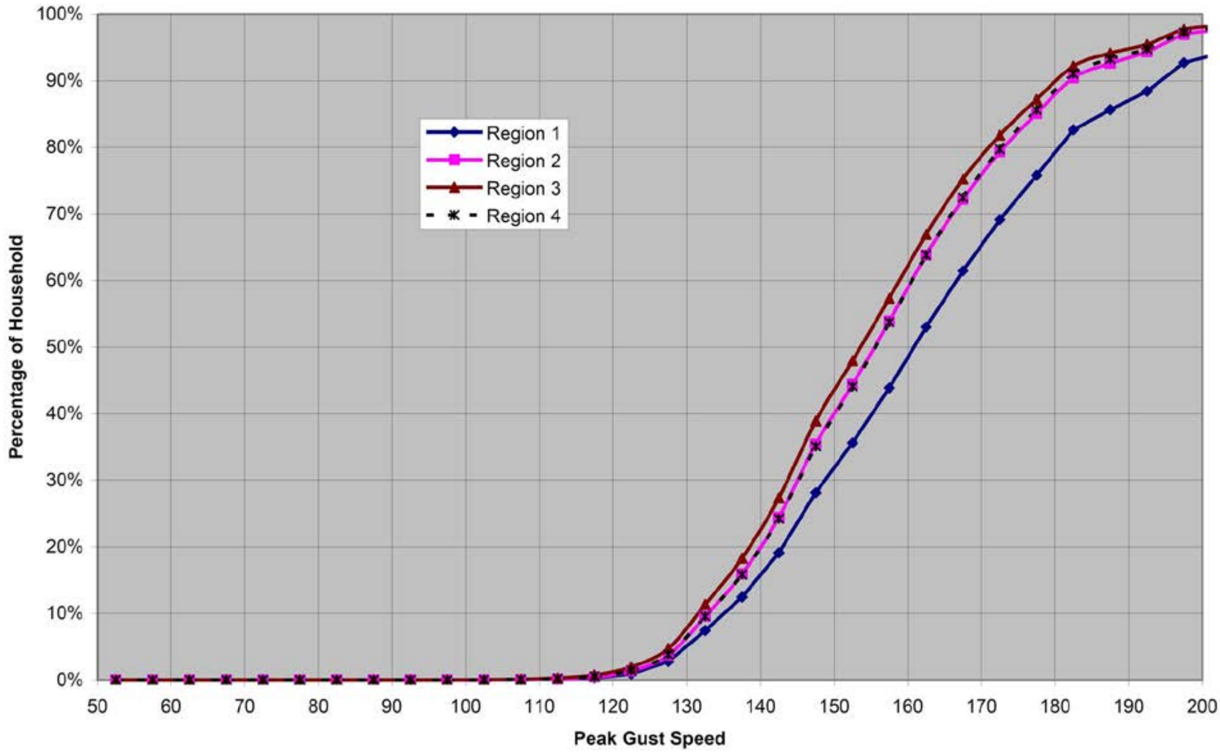


Building loss function (i.e., vulnerability curve) for a residential building



Content loss function (i.e., vulnerability curve) for a residential building

FIGURE 103. Internally displaced household persons as a function of peak gust wind speed (FEMA, 2013b)



5.4 FLOOD VULNERABILITY

The flood vulnerability of a building depends on topographic characteristics and location conditions in addition to the building's features.

These factors are considered when generating flood vulnerability maps and building vulnerability curves. The maps consider hazard, exposure, and fragility/consequence and evaluate vulnerable areas in the target area. The curves normally represent damage/loss percentage corresponding to flood intensity, such as inundation depth, and focus on one specific item at a time, such as buildings or fatalities. In this section, some past studies for both items are discussed.

5.4.1 FLOOD VULNERABILITY IN YANGON

One of the research projects performed by SATREPS studied the flood vulnerability of Yangon (Sritarapitat et al., 2018).

The researchers used data on the historical flood water surface and the master plan of the Yangon Region (see Figure 104) and then applied multi-criteria analysis by considering several flood factors, such as flow accumulation, distance from drainage, elevation, land cover, rainfall rate, slope, and soil type. As shown in Figure 104, the research team evaluated the spatial distribution of flood vulnerability of the region. The red color shows more vulnerable areas, while the blue color indicates less vulnerable areas (e.g., hillside areas with a higher altitude).

5.4.2 FLOOD-VULNERABLE LOCATIONS IN MYANMAR

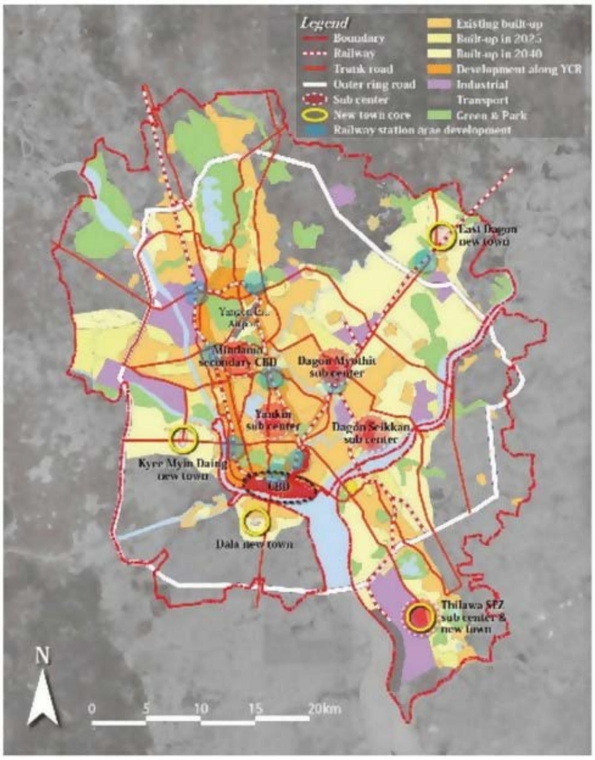
A report by DoM and DFID (2009) identifies Myanmar's most flood-prone areas; these include the catchment areas of major rivers and river basins (riverine flood), mountainous areas (flash flood), and coastal regions (secondary flood due to cyclone and storm) - see Figure 105.

5.4.3 FEDERAL EMERGENCY MANAGEMENT AGENCY

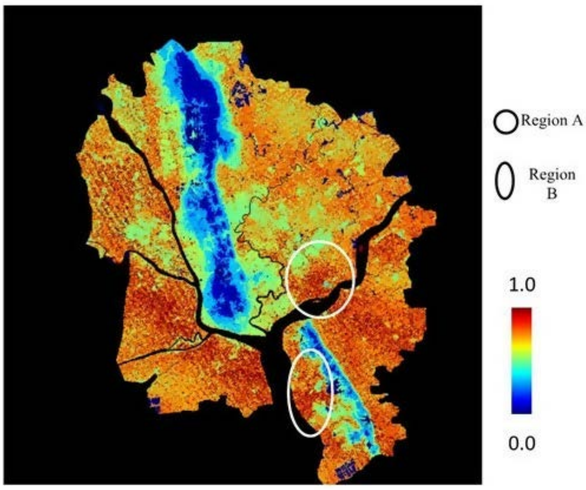
FEMA Hazus (FEMA, 2013) utilizes a vulnerability curve (or damage function) to estimate flood damage/loss corresponding to flood inundation depth.

Hazus combines an empirical and analytical method to develop vulnerability curves and assumed that the major structural components of a building would survive a flood, while the structural finishes and contents/inventory may be severely damaged due to inundation. The team then developed vulnerability curves for representative types of buildings and residential contents (see Figure 106). This type of function is useful to estimate the potential amount of damage/loss for each building.

FIGURE 104. City master plan and flood vulnerability map of Yangon (Sritarapitat et al., 2018)

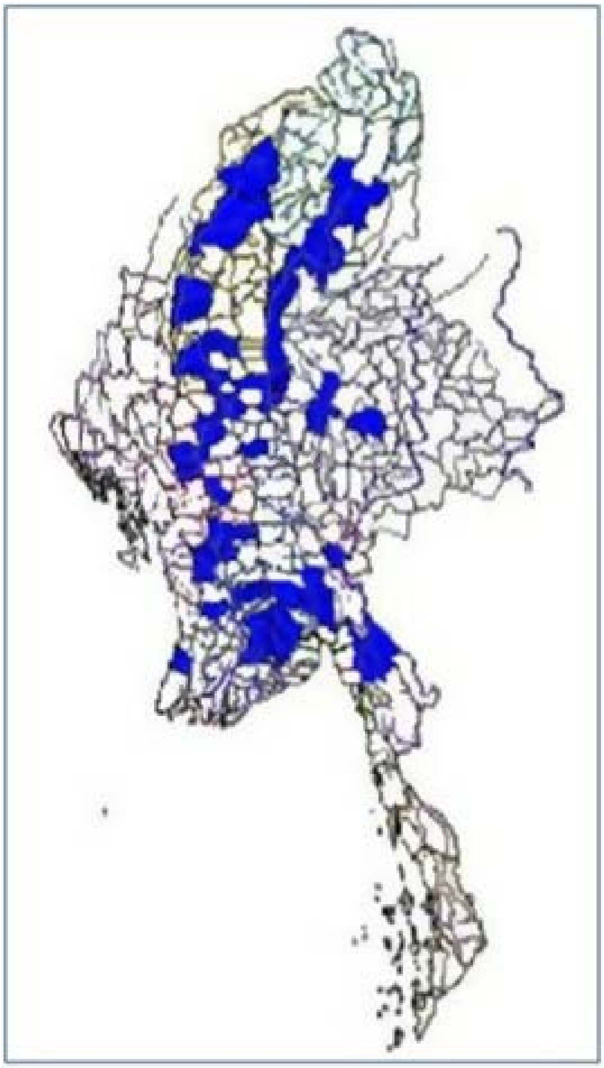


Master plan



Vulnerability map

FIGURE 105. Flood-prone areas in Myanmar (DoM and DFID, 2009)



5.4.4 OTHER REFERENCES

As part of its research to generate flood hazard maps, ADB (2016a-e) evaluated the spatial distribution of flood vulnerability in the Yangon Region.

The researchers utilized the flood hazard map developed by the project itself and applied it to two exposure models, for population and agriculture. The flood vulnerabilities for people and agriculture crops were then estimated for two flood scenarios: the 2007 flood case and a 100-year flood case (see Figure 107). This research shows that the flood vulnerability for any kind of objective (e.g., people, building, or infrastructure) can be estimated as long as an exposure model for that objective can be developed. This kind of VA is beneficial for preflood preparation and disaster reduction planning.

RHDHV (2018) proposes the development of two kinds of vulnerability curves – structural, and physical and social - for Myanmar in its future project. As an example, the project shows vulnerability curves consisting of inundation depth and damage ratio for residential buildings in Sri Lanka and Europe (see Figure 108). This curve is based on the same concept as the Hazus vulnerability curves described in the previous section.

Subsequently, as part of the Yangon Flood Model (YFM) by RHDHV (2019), an Urban Flood Risk Model was developed to generate a flood risk profile and spatial flood risk maps of the urban area by combining the flood depths at a certain probability (output of the Urban Flood Hazard Model) with the expected impact in terms of direct economic damage and loss of life (RHDHV, 2019).

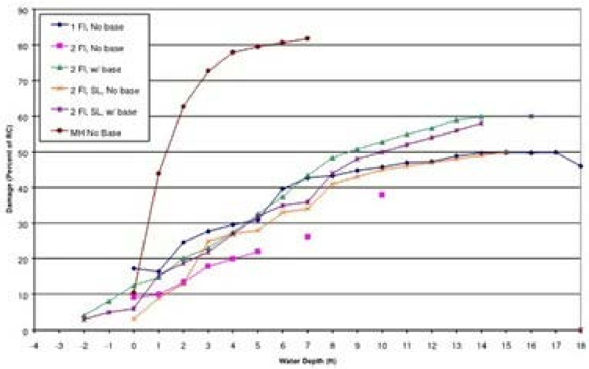
The flood risk model requires the input of a specific flooding scenario for which a flood risk analysis has to be prepared, flood hazard maps for different return periods prepared using the YFM (as described in Chapter 2.4.5 of this report), land use map, and vulnerability curves for each of the different land use classes distinguished.

The vulnerability curves used in the YFM were derived by HKV Consultants (2019) for various land use types, as detailed in the YFM report. Damage curves and maximum damage values are established for Yangon City based on articles from local sources and on methods proposed in global damage modelling publications. Table 25 below shows the land use types that have been distinguished for the preparation of the flood risk maps and their maximum damage values in Myanmar Kyat (MMK) and USD per m2. A Flood Risk Profile (FRP) for a selected sample scenario included in the YFM report contains a land use map, a maximum inundation map for each of the selected return periods, and damage maps showing damage caused for each of the selected return periods in terms of (i) economic damage, (ii) affected people, (iii) affected populations of concern, and (iv) critical infrastructure.

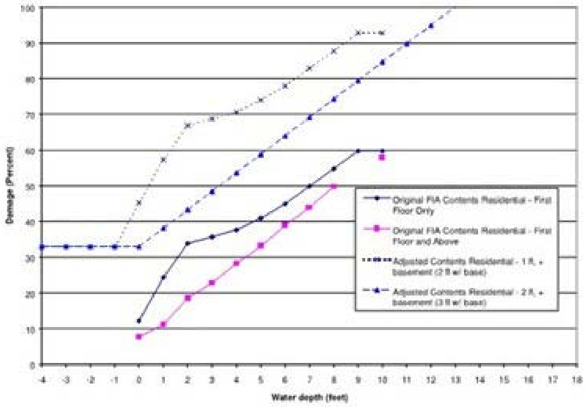
Land use types that have been distinguished for the preparation of the flood risk maps and their maximum damage values. RHDHV (2019),

The research conducted by the National Institute of Water and Atmospheric Research Ltd (NIWA, 2010) for New Zealand analyzes structural types of buildings (timber, masonry, and concrete) similar to those found in Myanmar. These curves can be used as a reference for the future development of vulnerability curves in Myanmar. As with the Hazus vulnerability curve, this curve is also composed of flood inundation depth and building damage ratio (see Figure 109).

FIGURE 106. Flood depth-damage curves for residential contents (FEMA, 2013b)

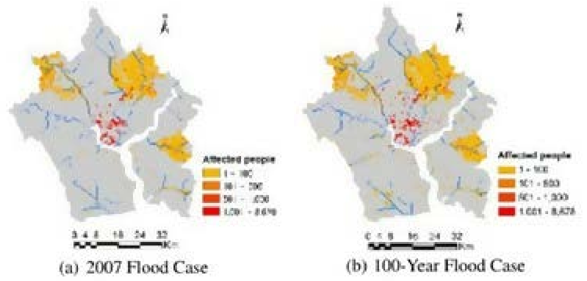


Buildings

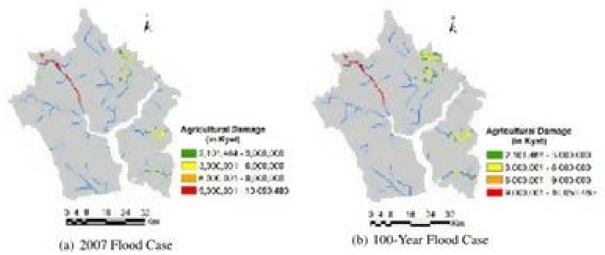


Residential content

FIGURE 107. Affected population and agricultural damage from flood in Yangon (ADB, 2016a-e)



Distribution of affected population



Agricultural damage

TABLE 25. Land use types that have been distinguished for the preparation of the flood risk maps and their maximum damage values. RHDHV (2019),

Land use types	Maximum damage value (MMK/m^2)	Maximum damage value (USD/m^2)*
Residential buildings	252,620	168
Commercial buildings	178,500	119,000
Industrial buildings	135,000	90
Roads	6,000	4
Critical infrastructure	830,558	55,3071

Note: Values are 2018 yearly average value: 1 MMK = 0.000666667 USD

FIGURE 108. Risk map for number of affected people, based on sample scenario (spring tide with high precipitation) in YFM (RHDHV, 2019)

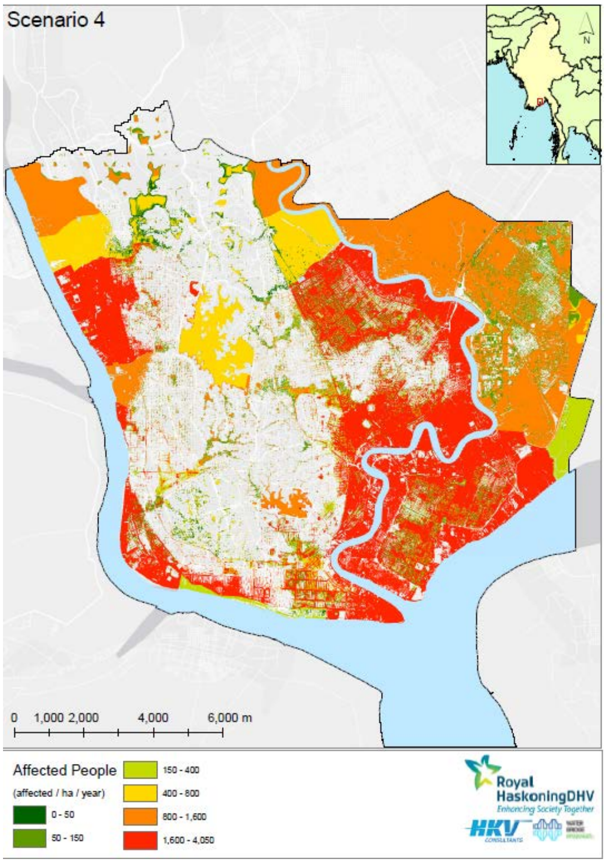
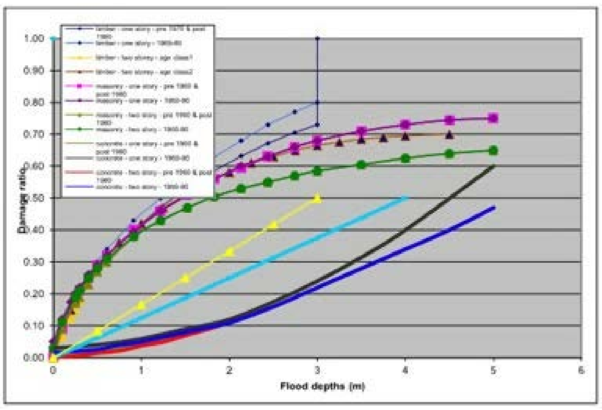


FIGURE 109. Flood vulnerability curves of various building types in New Zealand (NIWA, 2010)



Agricultural damage

5.5 FIRE VULNERABILITY

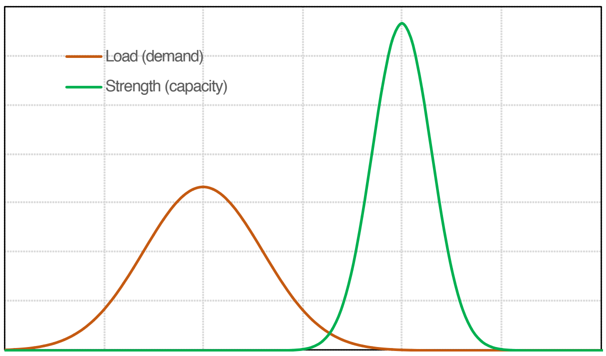
5.5.1 INTRODUCTION

Although a detailed VA of Yangon buildings for fire hazard has not been completed, laws, regulations, and code provisions are in place to investigate and address such vulnerability.

This is particularly the case for high-rise buildings. In structural design, due to uncertainties in demand (what is the actual load?) and capacity (what is the actual strength?), probabilistic methods are used to assess safety. An example of distribution for load (demand) and resistance (capacity or strength) is presented in Figure 110.

The overlapped curves correspond to failure. The margin (factor) of safety can be defined as the difference between the two curves in the Figure. The reliability index is defined based on the above distributions and probabilistic distribution of the failure.

FIGURE 110. Example of load and resistance distributions



5.5.2 RELIABILITY ANALYSIS

In a similar fashion, pairs of fire hazard parameters can be compared, and a reliability index can be computed to determine the vulnerability to fire.

Examples are presented in Table 25 (He, 2013).

The objectives of fire-resistant design, prescribed in the building codes and enforced during the permitting process, are to minimize human loss and structural damage in the affected building and decrease the likelihood of fire spreading to adjacent buildings. The fire severity depends on fire load and a number of other factors, as seen below:

$$Fire\ severity = (building\ height\ factor)*(sprinkler\ factor)*(fire\ load\ factor)*(ventilation\ factor)*(building\ material\ factor)*(building\ combustible\ material)$$

The addition of sprinklers results in a 50 percent reduction in fire severity. Garis et al. (2017) examined the effect of sprinkler systems on fire protection for residential buildings in Canada using data from fire agencies covering all fires from 2005 to 2015. In total, nearly 440,000 fire incidents were statistically analyzed.

TABLE 26. Example of parameters for conducting fire VA (He, 2013)

CASE	SAFETY PARAMETER	ON-SITE CONDITION
1	Required safe egress time	Available safe egress time
2	Fire resistance level	Fire severity

FIGURE 111. Methods of fire control for apartment buildings (Garis et al., 2017)

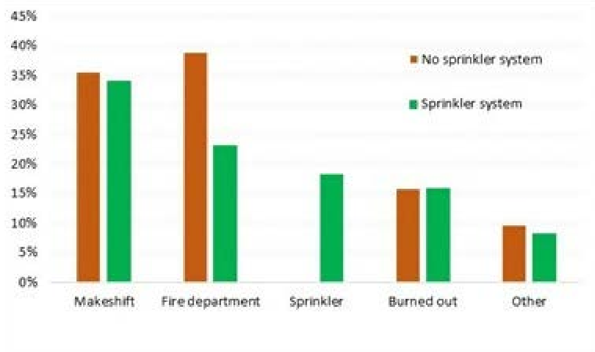
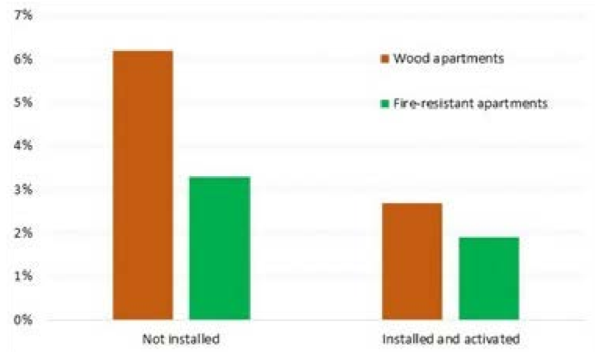


FIGURE 112. Fatality rates for apartment fires (Sekizawa, 2005)



The authors noted that (i) the fatality rates for residential buildings were three times higher for buildings without sprinklers compared to those with sprinkler systems; (ii) in buildings with sprinklers, significantly less intervention by the fire department was required (see Figure 111); and (iii) fires in buildings with sprinklers were smaller and more easily controlled compared to fires in buildings without sprinklers.

Sekizawa (2005) examined various factors contributing to fire fatalities. In particular, it was noted that the construction type and the condition of the fire alarm system had a significant impact on the fatality rate. As seen in Figure 112, there is a meaningful decrease in fire vulnerability and fatality ratio for fire-resistant apartments and when a fire alarm system is installed and activated.

5.5.3 NATIONAL FIRE PROTECTION ASSOCIATION ANALYSIS

The National Fire Protection Association (NFPA, 2019) provides guidelines for fire risk assessment (FRA).

FRA is usually conducted to determine the level of risk, mitigations measures, and reduction techniques or to provide general awareness and information to stakeholders. The risk tolerance depends on stakeholder perceptions.

The guidelines list several impacts to be considered during FRA on:

- People, including occupants and firefighters.
- Property, including the building structure.
- Financials, including business interruptions.
- Built environment, including heritage designations.
- Secondary impacts from hazardous material.

For successful FRA and mitigation, an acceptance criterion needs to be developed addressing the items identified above. Since risk can never be completely eliminated, the purpose of the acceptance criterion is to articulate what level of outcome can be considered acceptable. To that effect, NFPA recommended performing an uncertainty analysis as part of FRA.

NFPA lists the components of FRA as follows:

- Likelihood and consequence: developing a risk matrix.
- Concepts and systems: selecting a methodology.
- Fire scenarios: selecting cases for analysis.

MFPA identifies several FRA methods based on whether the likelihood and consequences are being treated qualitatively or quantitatively and whether a cost-benefit analysis is performed.

5.6 DISCUSSION

5.6.1 SEISMIC VULNERABILITY

RVS of the Kyauktada Township showed the following:

- Over 45 percent of the surveyed buildings were low-rise structures. As discussed in this report, the level of compliance to the MNBC seismic provisions is voluntary for new low-rise buildings, while the most stringent requirements are applied to high-rise buildings.
- Over 40 percent of the buildings were URM, one of the most vulnerable building constructions for earthquake events. RC buildings, if properly designed, will perform well in earthquakes. However, RC buildings that are not constructed properly or have non-ductile detailing perform poorly in earthquakes.

- Over 54 percent of buildings were constructed before 1980. RC buildings of this age typically use non-ductile details and are therefore susceptible to damage from earthquakes. Another 35 percent were constructed before 2003 and might have non-ductile or low-ductility construction. Finally, even for newer buildings, the seismic performance is highly dependent on construction quality.

RVS of four additional downtown townships showed that nearly 70 percent of buildings have low vulnerability against earthquakes. The remaining 30 percent of buildings - over 1,300 structures - would require additional investigation and possible strengthening.

Analytical studies of three RC buildings in three townships showed that building performance was inadequate; in particular, a high likelihood of collapse in the event of a severe earthquake was observed. In modern codes, buildings are designed to have on average a probability of collapse of 10 percent or below in the event of a severe earthquake. For Yangon RC buildings, this probability is significantly higher and points to the need for seismic retrofitting.

5.6.2 CYCLONE VULNERABILITY

While some studies (DMH, 2018; HARP and MIMU, 2018) have identified cyclone-prone areas in Myanmar, detailed vulnerability maps considering possible cyclone damage or loss have not yet been developed.

Vulnerability curves for buildings or human loss from cyclone hazards have never been generated either. Institutions like FEMA Hazus have generated vulnerability curves for hurricane hazards; it would be valuable to explore the possibility of applying their methodologies to the development of vulnerability curves for building damage and social loss in Myanmar. Once these vulnerability curves have been established, they can be combined with cyclone hazard and exposure model to produce a cyclone vulnerability map and assessment for disaster damage reduction.

5.6.3 FLOOD VULNERABILITY

Some research has been conducted on the flood vulnerability of Yangon (Sritarapitat et al., 2018; DoM and DFID, 2009; ADB, 2016a-e).

Similarly, studies on vulnerability curves for building types (i.e., damage ratio and flood depth relationship) have been completed in some countries and regions in the world (FEMA, 2013; NIWA, 2010). However, no analysis has been performed to estimate fatalities or building damages due to flood disaster in Yangon. In addition to the importance of flood hazard maps and fragility function development, a VA considering the built environment and spatial flood hazard level in Yangon is also essential in understanding the expected damage and loss caused by a disastrous flood in order to provide effective countermeasures.

5.6.4 FIRE VULNERABILITY

Research shows that the key components in reducing vulnerability to fire hazard and demand for firefighting services are:

- Ensuring that buildings are equipped with working and properly designed sprinkler systems.
- For vulnerable buildings (such as wood buildings), ensuring that a functioning alarm/detection system is installed.
- FRA analysis can be used to assess the likelihood and consequences of fire scenarios. To account for unknown factors and assumptions, uncertainty analysis can be conducted. FRA analysis allows the impact of fire hazard on people and property to be assessed, and can be used by the authority having jurisdiction and other stakeholders (such as the city) to define the tolerable level of risk and to develop a mitigation strategy.

The provisions in the building code can be used and revised as needed to enforce fire-resistance measures.

6. Damage Assessment and Consequences

6.1 OVERVIEW

In examining the performance of the built environment, researchers can draw conclusions to support the improvement of building code provisions and construction industry methods and to identify the need for academic research.

Accordingly, it is important to develop and implement a robust damage assessment program ahead of likely events to allow for the rapid reoccupation of safe buildings. Furthermore, the collected data form a valuable database to be used in future development. For example, in the aftermath of the 2010 Haiti earthquake, rapid damage assessments (RDAs) of over 400,000 buildings were performed, and a database was developed and used to identify the key factors contributing to damage.

To date, it does not appear that a comprehensive damage assessment program has been implemented for Yangon or Myanmar, as evident in the lack of data from Cyclone Nargis, recent earthquakes, and floods.

6.2 EARTHQUAKE DAMAGE ASSESSMENT

The Applied Technology Council document (ATC)-20 (ATC, 2005) has been used for several years in the USA to record earthquake damage.

The modified version of this document has been used worldwide, including by countries within the Association of Southeast Asian Nations (ASEAN) such as the Philippines and Indonesia, after recent earthquakes.

The ATC-20 RDA form is presented in Figure 113. The main section of the document, similarly to other post-disaster RDA forms, includes:

- Assessor information and time of inspection.
- Building name and location (GPS and address).
- Building occupancy.
- Building's approximate footprint and number of stories.
- Building framing and material.
- Overall DS and level of damage for key components.
- Building tag (green, yellow, or red).
- Further recommendations, such as conducting detailed damage assessments or geotechnical assessments.

Successful implementation of an RDA program relies on training a sufficient number of qualified evaluators. In the USA, the Safety Assessment Program, consisting of classroom education and practical examples, is used to train both trainers and trainees. Modified versions of this program have been successfully implemented in developing countries; in these cases, a field practice component was included to provide additional experience.

In Yangon, UN-Habitat conducted an RDA class at the YTU campus in 2017 (UN-Habitat, 2017). The next step would be to adapt the RDA forms to Myanmar based on ATC-20 and to train a sufficient number of evaluators to support program implementation. A web-based evaluators directory needs to be prepared for use by the Department of Disaster Risk Management (DDM) in the aftermath of an earthquake.

6.3 CYCLONE AND WIND DAMAGE ASSESSMENT

No damage assessment frameworks for cyclone disasters have been found in Myanmar; this type of assessment process needs to be developed as soon as possible. In other countries, several types of damage assessment methodologies are in place and used is post-disaster situations. In this section, an assessment methodology developed in the USA is shown as a reference, and a new technology that identifies cyclone damage remotely is introduced.

6.3.1 ATC-45

ATC-45 Field Manual: Safety Evaluation of Buildings After Windstorms and Floods (ATC, 2004) has been utilized to evaluate and record hurricane damage of buildings in the USA.

The assessment is used to determine whether damaged or potentially damaged buildings are safe for use, or if entry should be restricted or prohibited (i.e., “Inspected safe (Green placard),” “Restricted use (Yellow placard)” or “Unsafe (Red placard)”). The Manual provides two types of assessment methodologies: rapid and detailed assessments.

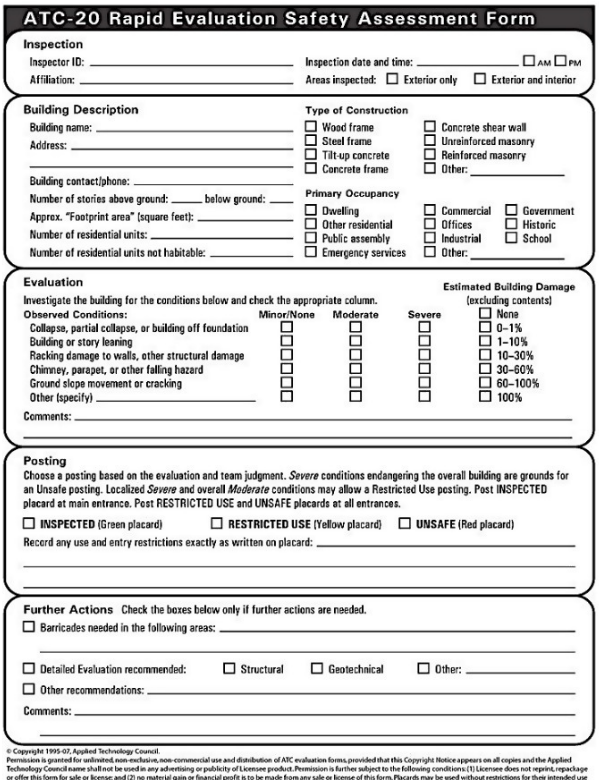
As the assessment form for rapid safety evaluation shows in Figure 114, the main evaluation items are basic information, structural characteristics, and damage status and safety evaluation of buildings, as itemized below:

- Inspection information (inspector name, inspection date and time, and inspected area).
- Building information (location, volume, height, footprint, structure type, and occupancy).
- Damage evaluation (structural, non-structural, falling, geotechnical, electrical, and other hazards).
- Safety posting (safety-level placard, entry restriction, and additional comments).
- Further recommendations (barricades necessity, additional structural damage assessment, geotechnical investigation, and additional comments).

6.3.2 SATELLITE IMAGERY DAMAGE ASSESSMENT

Instead of a traditional damage assessment format such as ATC-45, a novel technology using satellite imagery is applied to a remote identification procedure for cyclone-induced damage over a large area (Hoque et al., 2015). This methodology uses remote sensing information, such as satellite imagery, and applies the object-based image classification technique to map land cover types in pre- and post-cyclone satellite imagery. The post-classification change detection technique identifies types of land cover changes caused by cyclone damage. As shown in Figure 115, the researcher conducted a test study of the proposed methodology by applying the imageries of Sarankhola upazila in Bangladesh, hit by Cyclone Sidr in 2007. Based on the classified land cover differences, damaged areas such as closed water bodies, ground without crops, debris, and sparse vegetation can be detected. The capability of the methodology was demonstrated; however, the author specified that some improvements are required.

FIGURE 113. Replica of ATC-20 (ATC, 2005)



ATC-20 Rapid Evaluation Safety Assessment Form

Inspection

Inspector ID: ______ Inspection date and time: ______ ☐ AM ☐ PM
Affiliation: ______ Areas inspected: ☐ Exterior only ☐ Exterior and interior

Building Description

Building name: ______
Address: ______
Building contact/phone: ______
Number of stories above ground: ______ below ground: ______
Approx. "Footprint area" (square feet): ______
Number of residential units: ______
Number of residential units not habitable: ______

Type of Construction
☐ Wood frame ☐ Concrete shear wall
☐ Steel frame ☐ Unreinforced masonry
☐ Tilt-up concrete ☐ Reinforced masonry
☐ Concrete frame ☐ Other: ______

Primary Occupancy
☐ Dwelling ☐ Commercial ☐ Government
☐ Other residential ☐ Offices ☐ Historic
☐ Public assembly ☐ Industrial ☐ School
☐ Emergency services ☐ Other: ______

Evaluation

Investigate the building for the conditions below and check the appropriate column.

Observed Conditions:	Minor/None	Moderate	Severe	Estimated Building Damage (excluding contents)
				☐ None
Collapse, partial collapse, or building off foundation	☐	☐	☐	☐ 0–1%
Building or story leaning	☐	☐	☐	☐ 1–10%
Racking damage to walls, other structural damage	☐	☐	☐	☐ 10–30%
Chimney, parapet, or other falling hazard	☐	☐	☐	☐ 30–60%
Ground slope movement or cracking	☐	☐	☐	☐ 60–100%
Other (specify) ______	☐	☐	☐	☐ 100%

Comments: ______

Posting

Choose a posting based on the evaluation and team judgment. *Severe* conditions endangering the overall building are grounds for an Unsafe posting. Localized *Severe* and overall *Moderate* conditions may allow a Restricted Use posting. Post INSPECTED placard at main entrance. Post RESTRICTED USE and UNSAFE placards at all entrances.

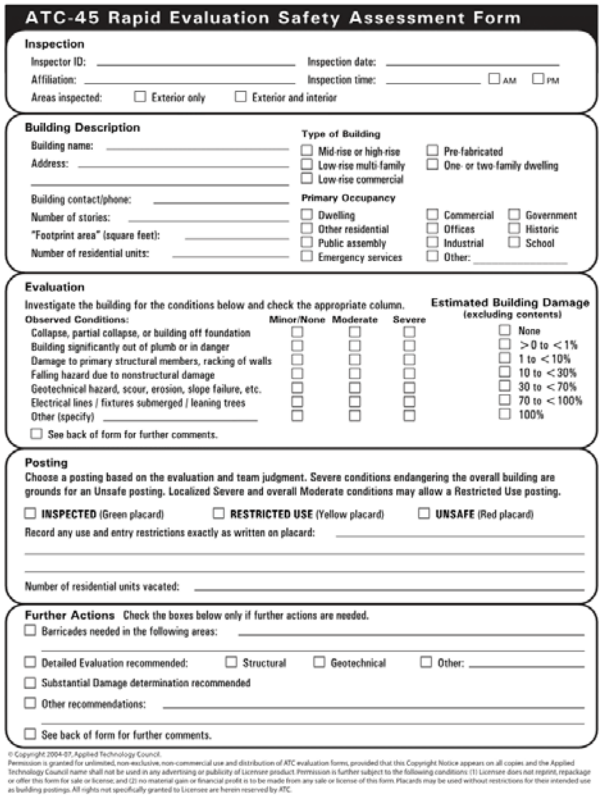
☐ **INSPECTED** (Green placard) ☐ **RESTRICTED USE** (Yellow placard) ☐ **UNSAFE** (Red placard)

Record any use and entry restrictions exactly as written on placard: ______

Further Actions Check the boxes below only if further actions are needed.

☐ Barricades needed in the following areas: ______
☐ Detailed Evaluation recommended: ☐ Structural ☐ Geotechnical ☐ Other: ______
☐ Other recommendations: ______
Comments: ______

FIGURE 114. Replica of ATC-45 (ATC, 2004)



ATC-45 Rapid Evaluation Safety Assessment Form

Inspection

Inspector ID: ______ Inspection date: ______
Affiliation: ______ Inspection time: ______ ☐ AM ☐ PM
Areas inspected: ☐ Exterior only ☐ Exterior and interior

Building Description

Building name: ______
Address: ______
Building contact/phone: ______
Number of stories: ______
"Footprint area" (square feet): ______
Number of residential units: ______

Type of Building
☐ Mid-rise or high-rise ☐ Pre-fabricated
☐ Low-rise multi-family ☐ One- or two-family dwelling
☐ Low-rise commercial

Primary Occupancy
☐ Dwelling ☐ Commercial ☐ Government
☐ Other residential ☐ Offices ☐ Historic
☐ Public assembly ☐ Industrial ☐ School
☐ Emergency services ☐ Other: ______

Evaluation

Investigate the building for the conditions below and check the appropriate column.

Observed Conditions:	Minor/None	Moderate	Severe	Estimated Building Damage (excluding contents)
Collapse, partial collapse, or building off foundation	☐	☐	☐	☐ None
Building significantly out of plumb or in danger	☐	☐	☐	☐ >0 to <1%
Damage to primary structural members, racking of walls	☐	☐	☐	☐ 1 to <10%
Falling hazard due to nonstructural damage	☐	☐	☐	☐ 10 to <30%
Geotechnical hazard, scour, erosion, slope failure, etc.	☐	☐	☐	☐ 30 to <70%
Electrical lines / fixtures submerged / leaning trees	☐	☐	☐	☐ 70 to <100%
Other (specify) ______	☐	☐	☐	☐ 100%

☐ See back of form for further comments.

Posting

Choose a posting based on the evaluation and team judgment. Severe conditions endangering the overall building are grounds for an Unsafe posting. Localized Severe and overall Moderate conditions may allow a Restricted Use posting.

☐ **INSPECTED** (Green placard) ☐ **RESTRICTED USE** (Yellow placard) ☐ **UNSAFE** (Red placard)

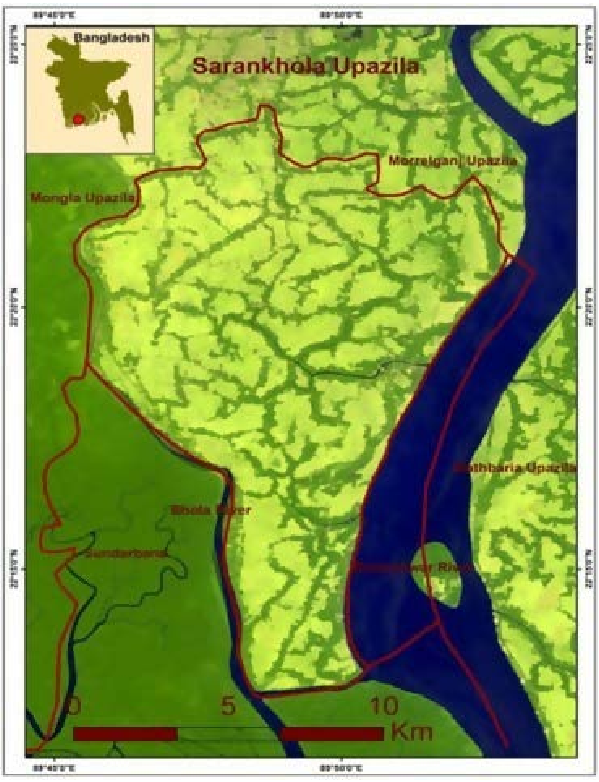
Record any use and entry restrictions exactly as written on placard: ______

Number of residential units vacated: ______

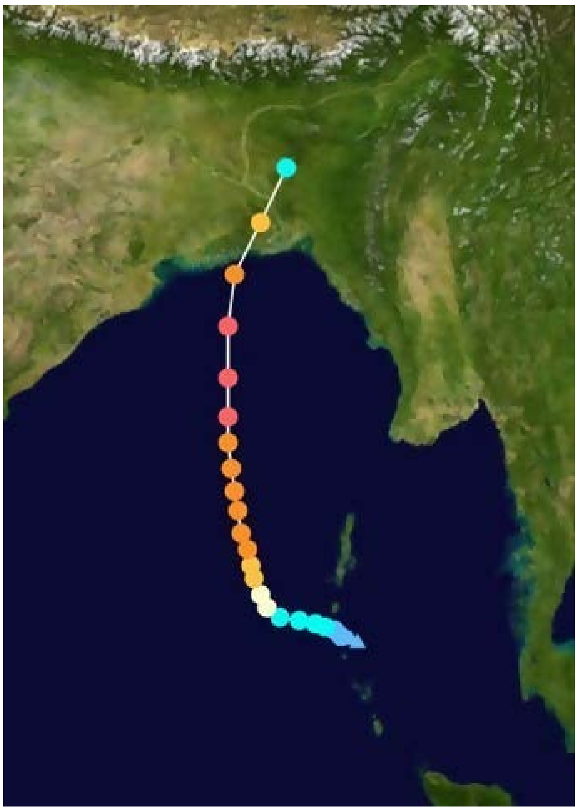
Further Actions Check the boxes below only if further actions are needed.

☐ Barricades needed in the following areas: ______
☐ Detailed Evaluation recommended: ☐ Structural ☐ Geotechnical ☐ Other: ______
☐ Substantial Damage determination recommended
☐ Other recommendations: ______
☐ See back of form for further comments.

FIGURE 115. Pre- and post-cyclone images of the study area (Hoque et al., 2015)

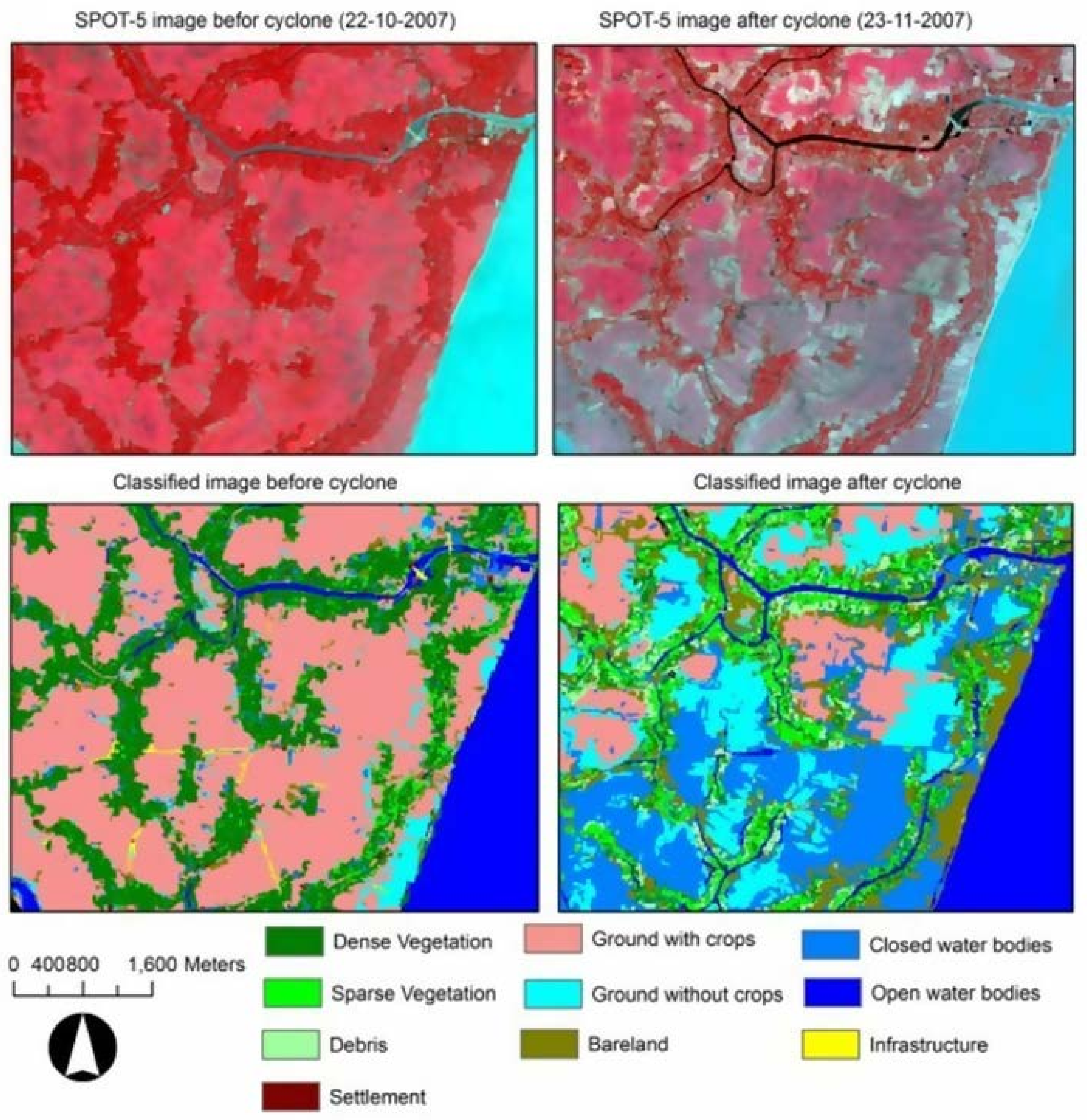


Study area: Sarankhola upazila under Bagerhat district in Bangladesh



Study cyclone: track of Cyclone Sidr

FIGURE 115. Pre- and post-cyclone images of the study area (Hoque et al., 2015) (Continued)



6.4 FLOOD DAMAGE ASSESSMENT

An official form to assess building damage due to flood has not yet been established in Myanmar; an assessment framework that considers the country's unique circumstances needs to be developed for post-disaster response.

In the USA, ATC-45 (ATC, 2004) manual has been utilized to evaluate and record flood damage of buildings and determine whether damaged or potentially damaged buildings are safe for use, or if entry should be restricted or prohibited. The manual provides two types of evaluation procedures: rapid and detailed evaluations. As the assessment form for rapid safety evaluation shows in Figure 115, the main evaluation items are basic information, structure characteristics, damage status, and safety evaluation of buildings, as itemized below:

- Inspection information: inspector name, inspection date and time, and inspected area.
- Building information: location, volume, height, footprint, structure type, and occupancy.
- Damage evaluation: structural, non-structural, falling, geotechnical, electrical, and other hazards.
- Safety posting: safety-level placard, entry restriction, and additional comments.
- Further recommendations: barricades necessity, additional structural damage assessment, geotechnical investigation, and additional comments.

6.5 FIRE DAMAGE ASSESSMENT

6.5.1 RECENT FIRE STATISTICS

Statistical data for fires in Yangon are provided and synthesized in this section (FSD, 2019).

Two sets of fire statistics data were available: 2009–2018 and 2016–2018.

- Fires resulting from negligence/accidental and electrical account for 80–90 percent of all fires in the city. This finding is almost constant over both data sets (see Figure 116).
- Residential houses were by far the most affected by urban fires. However, a number of fires in factories and warehouses were also recorded (see Figure 117).
- The consequences of Yangon fires in the past three years are summarized in Table 26. Note that urban fires have a significant human and financial impact on the city.
- A ten-year period provides a large enough sample to make annual predictions for the city. As shown in Table 26, the expected fatalities and injuries on an annual basis due to urban fires are 12 and 45, respectively. The fires displace close to 1,000 people every year and cost just over US$8 million.

TABLE 27. Consequences of fires in Yangon, 2016–2018 (FSD, 2019)

	2016	2017	2018 (NINE MONTHS)
Fatalities	4	22	4
Injured	45	26	28
Displaced	301	552	698
Financial loss	$25,484,000	$ 26,925,000	$ 714,000

TABLE 28. Consequences of fires in Yangon, ten-year period (FSD, 2019)

YEAR	FATALITIES	INJURED	DISPLACED	FINANCIAL LOSS
2009	8	27	145	$ 6,400,000
2010	11	14	597	$ 16,500,000
2011	23	113	1,528	$ 300,000
2012	5	20	1,908	$ 3,100,000
2013	26	54	1,238	$ 300,000
2014	6	55	307	$ 300,000
2015	10	41	2,116	$ 300,000
2016	4	45	301	$ 25,500,000
2017	22	26	552	$ 27,000,000
2018 (nine months)	8	59	775	$ 900,000
Total	**123**	**454**	**9,467**	**$ 80,600,000**
Average	**12**	**45**	**946**	**$ 8,060,000**

6.6 DISCUSSION

6.6.1 EARTHQUAKE DAMAGE ASSESSMENT

The development of a post-earthquake damage assessment program is the first step toward recovery.

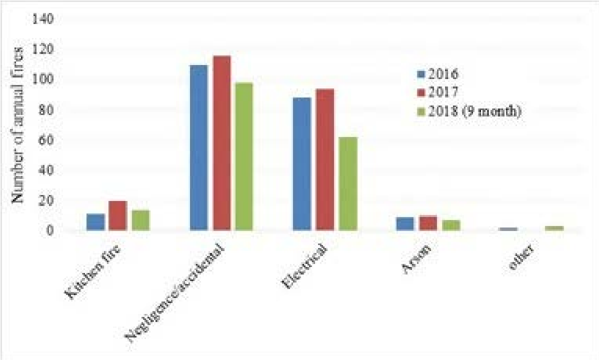
In the aftermath of an earthquake, residents would naturally be concerned about the safety of all buildings. By surveying the damage and determining which buildings are safe to reoccupy, resources can be redirected to other concerns. The development of a damage assessment form and training a sufficient number of evaluators are key to achieving this goal. Maintaining a searchable database of trained and certified evaluators will also allow them to be contacted and swiftly dispatched to the impacted areas.

6.6.2 CYCLONE DAMAGE ASSESSMENT

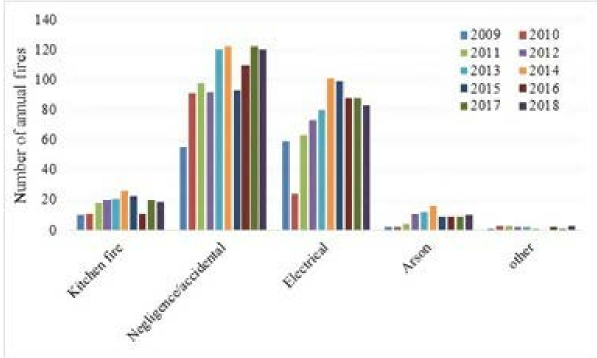
In order to expedite the disaster response and recovery procedures, a damage assessment framework needs to be developed and implemented in Myanmar.

At the same time, a database system for inspection results of not only damage but also cyclone intensity is needed. This database would facilitate future research on cyclone hazard, fragility, and vulnerability. The use of satellite images for disaster damage assessment and the development of a disaster exposure model is under research. The development and application of this type of technology supports the assessment of cyclone damage in Myanmar because accessibility to damaged areas could be difficult after a cyclone disaster.

FIGURE 116. Causes of fire in Yangon, 2009–2018 (FSD, 2019)

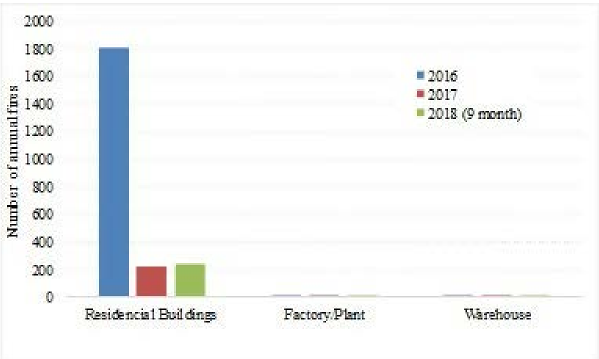


2016–2018

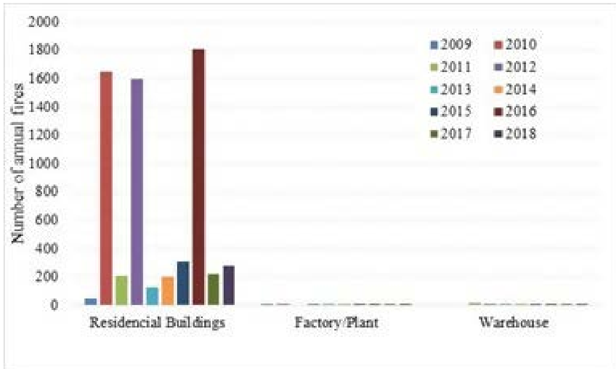


2009–2018

FIGURE 117. Buildings affected by fire in Yangon 2016–2018 (FSD, 2019)



2016–2018



2009–2018

6.6.3 FLOOD DAMAGE ASSESSMENT

Damage assessment after a flood or other disaster is one of the most important measures for disaster resilience and quick recovery since damage evaluation and reparability assessment is the starting point for repair or reconstruction.

A damage assessment form and a framework for the training of inspectors need to be established as soon as possible in Myanmar. This kind of assessment is beneficial not only for building damage investigation but also flood level identification (e.g., inundation depth, inundated area, etc.). In addition, the data would facilitate future research projects relating to floods, such as hazard map creation and flood disaster risk reduction.

6.6.4 FIRE DAMAGE ASSESSMENT

For urban fires, FSD currently collects data on the probable cause of fire, building occupancy type, and consequences.

In the immediate aftermath of the fire, the objective is to extinguish the fire to reduce the likelihood of human and financial losses. In the aftermath of the fire and during the investigation phase, it is recommended that additional data on the structure be collected. This data could include items such as GPS coordinates of the building, number of stories, construction material, and building occupancy. FSD indicated the existence of maps that show the location of townships; it is recommended that such maps be developed and uploaded on the server. Some of the data collected during the investigation could be included in the searchable online database.

7. Disaster risk management

7.1 OVERVIEW

Myanmar is ranked third globally for occurrence of extreme events in the 1998–2017 period (Germanwatch, 2019).

Myanmar HCT developed a qualitative risk analysis matrix by considering the probability of a risk occurring and the impact of such risk, as shown in Table 28 (HCT, 2016); such an analysis allows decision-makers to allocate resources for DRM by prioritizing risks. The natural hazards discussed in this report rank as critical or severe for the country. For Yangon, urban fire is also a severe or critical hazard.

At the same time, the country ranks among the 12 countries with the highest values in the hazard and exposure dimension, and is also high in lack of coping capacity (INFORM, 2019). It is therefore critical to plan and implement a robust DRM program in the country and Yangon in particular. Pre-event VA and post-event damage assessment, discussed previously in this report, are two critical components of a successful DRM program. This section discusses other DRM components completed or currently under investigation for Yangon.

7.2 RISK PERCEPTION

A key component of risk planning is educating the public, as people's perception of risk affects their preparedness and response.

An important study was recently completed which included surveys conducted in the Pazuntaung and Tamwe Townships (Fernandeza et al., 2018). In total, 213 respondents participated in the survey, and 199 complete samples were collected.

Table 29 presents the survey participants' perception of likelihood of natural hazards occurring in the next 10 years. Less than 10 percent of respondents perceived any of the natural hazards being likely in a 10-year period. The authors attributed the low values, especially for fire, to the prevalence of urban fires in the city.

TABLE 29. Qualitative natural risk analysis matrix (HCT, 2016)

		PROBABILITY OF OCCURRENCE				
		VERY UNLIKELY	UNLIKELY	MODERATELY LIKELY	LIKELY	VERY LIKELY
	NEGLIGIBLE					
	MINOR			Fire		
IMPACT	**MODERATE**					
	SEVERE				Flood	
	CRITICAL		Tsunami	Earthquake	Cyclone	

TABLE 30. Perceived likelihood of natural disasters (Fernandeza et al., 2018)

		PERCEIVED PROBABILITY OF OCCURRENCE				
		VERY UNLIKELY	UNLIKELY	NEUTRAL	LIKELY	VERY LIKELY
	FIRE	37%	30%	28%	4%	1%
HAZARD	**EARTHQUAKE**	5%	41%	47%	6%	1%
	CYCLONE	5%	45%	46%	4%	0%

Table 30 shows the perceived impact (loss of life) of natural hazards. Only 30–35 percent of respondents considered any of the hazards as having serious or very serious impacts.

Table 31 presents the perceived knowledge of mitigation for the hazards. Approximately 15 percent of respondents are clear or very clear regarding fire mitigation, while less than 10 percent are clear or very clear regarding other hazards. Residents are more versed in responding to fire because of the regular occurrence of urban fires and their experience in controlling them.

The results of this and similar studies can be used as part of the DRM strategy for decision-makers and to encourage public support for such programs.

7.3 MYANMAR CONSORTIUM FOR CAPACITY DEVELOPMENT ON DISASTER MANAGEMENT

A disaster management handbook for Myanmar was prepared by the Center for Excellence in Disaster Management and Humanitarian Assistance (CFE-DM, 2017).

The authors noted that worldwide, Yangon is the fifth most vulnerable city to the effects of climate change. They also noted that disaster risk response (DRR) was in its initial stages in the country and, while there was limited capacity to address this shortcoming, the Government had established the Disaster Management Training Centre (DMTC) to enhance the capacity of DRM implementers. The Myanmar Consortium for Capacity Development on Disaster Management (MCCDDM) project was sponsored by the U.S. Agency for International Development (USAID) and completed in 2018 (USAID, 2018).

TABLE 31. Perceived impact (loss of life) of natural disasters (Fernandeza et al., 2018)

		PERCEIVED IMPACT				
		NOT SERIOUS	LITTLE SERIOUS	NEUTRAL	SERIOUS	VERY SERIOUS
HAZARD	FIRE	9%	26%	34%	28%	4%
	EARTHQUAKE	6%	24%	36%	31%	4%
	CYCLONE	7%	30%	37%	23%	3%

TABLE 32. Perceived preparedness of natural disasters (Fernandeza et al., 2018)

		PERCEIVED PREPAREDNESS				
		VERY UNCLEAR	UNCLEAR	NEUTRAL	CLEAR	VERY CLEAR
HAZARD	FIRE	5%	35%	47%	9%	4%
	EARTHQUAKE	15%	46%	31%	5%	3%
	CYCLONE	15%	47%	32%	2%	4%

The objectives of MCCDDM were to support DMTC in (i) upgrading the capacity of DRM implementers; (ii) training the DRM trainers as experts; and (iii) increasing public awareness in regard to DRM.

7.4 MYANMAR ACTION PLAN ON DISASTER RISK REDUCTION

In Myanmar, DRM laws and rules were enacted in 2015. The National Disaster Management Committee (NDMC) is a high-level committee that oversees risk management and response.

The Committee's organization flowchart for DRM in Myanmar is presented in Figure 118 (NDMC and MAPDRR, 2017). In the aftermath of the 2008 Cyclone Nargis, a DRR working group was established to assist in recovery. At the national level, the United Nations Development Programme (UNDP) serves as the chair of the working group. The private sector also participated in the DRR.

The Union of Myanmar Federation of Chambers of Commerce and Industry (UMFCCI) and UNDP have established a private sector DRM network.

- The Myanmar Action Plan on Disaster Risk Reduction (NDMC and MAPDRR, 2017) includes three phases:
- Setting up policies for DRM and generating information for risk reduction.
- Implementing large-scale DRR.
- Institutionalizing risk reduction and developing steps towards resilience.
- Some of the priority actions included in MAPDRR relevant to vulnerability in Yangon are:
- National multi-hazard risk assessment.
- Nationwide disaster awareness program.
- Myanmar DRM policy and relief guidelines.
- Strengthening fire risk management.
- Mainstreaming DRR into regional development planning.

FIGURE 118. NDMC organization flowchart (adapted from NDMC and MAPDRR, 2017)

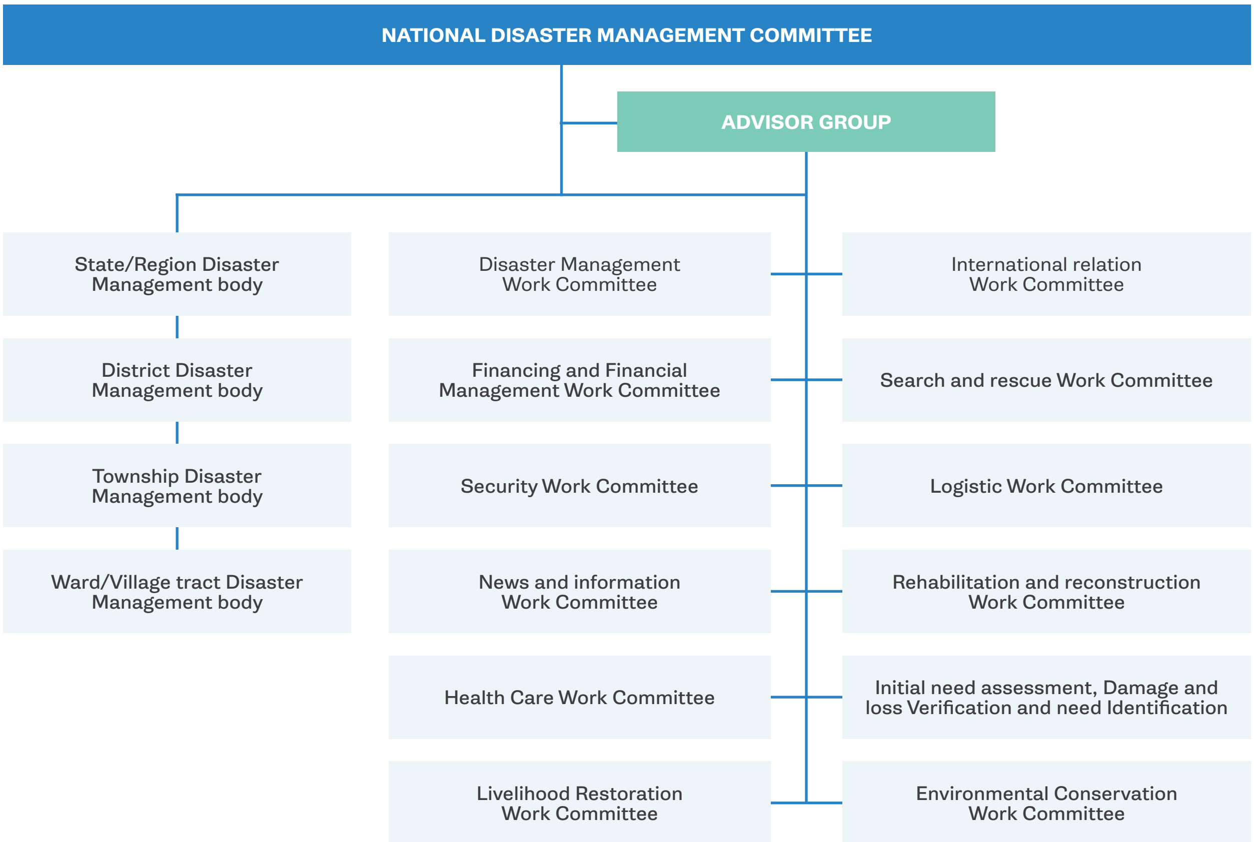
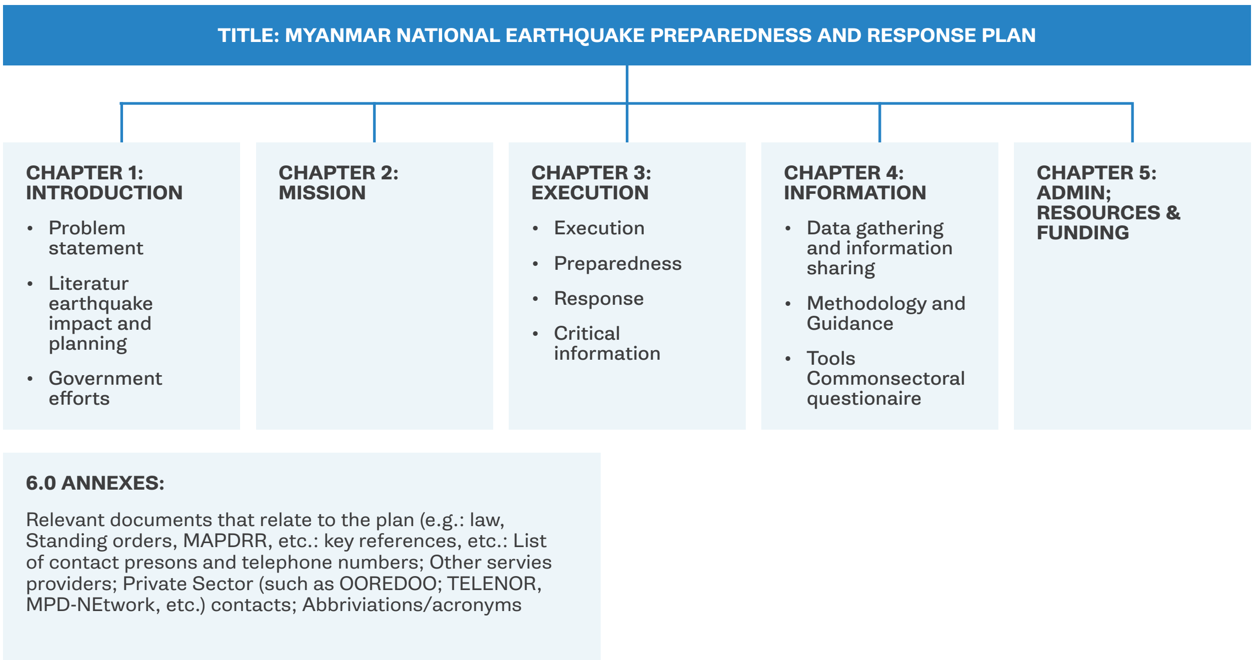


FIGURE 119. Outline of the national earthquake response plan (adapted from UNDP, 2018)



7.5 DRR COMPONENT OF THE YANGON EARTHQUAKE FORUM

The second Earthquake Forum was conducted in July 2018 in Yangon.

Some of the presenters discussed DRR and community resilience; key points from these presentations are summarized in this section.

7.5.1 UNITED NATIONS DEVELOPMENT PROGRAMME PROJECT FOR EARTHQUAKE RESILIENCE

The project was funded by the European Civil Protection and Humanitarian Aid Operations and included three components: (i) building earthquake preparedness and response capacities of government institutions; (ii) promoting community awareness; and (iii) providing access to earthquake risk information and data for all stakeholders. The project team developed a national earthquake preparedness and response plan (see Figure 119), conducted a media campaign to educate the public on earthquake hazard, and developed a national earthquake resilience strategy.

7.5.2 MYANMAR PRIVATE SECTOR DISASTER MANAGEMENT NETWORK

The Myanmar Private Sector Disaster Management Network (MPD) is a public-private partnership between the Government and UMFCCI aimed to address risk.

It has 100 members as of 2018 (Pun, 2018), and encourages businesses to participate as it recognizes that natural hazards have adverse implications for people, the built environment, and businesses. MPD's objectives are illustrated in Figure 120.

7.5.3 YANGON CITY DEVELOPMENT COMMITTEE RESPONSE PLAN

YCDC is undertaking the task of earthquake DRM for the city.

The key components of the program, presented in Figure 121 (Win, 2018b), include:

- Preparing a strategic plan for seismic retrofit of reconstruction of vulnerable buildings.
- Developing a warning and emergency response plan.
- Allowing for temporary shelters in the event of a disaster.

FIGURE 120. MPD's objectives (adapted from Pun, 2018)

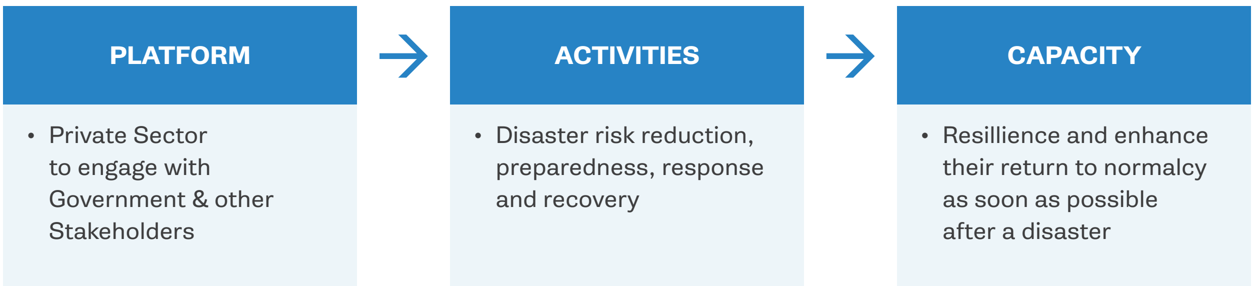


FIGURE 121. YCDC earthquake preparedness plan (Win, 2018a)

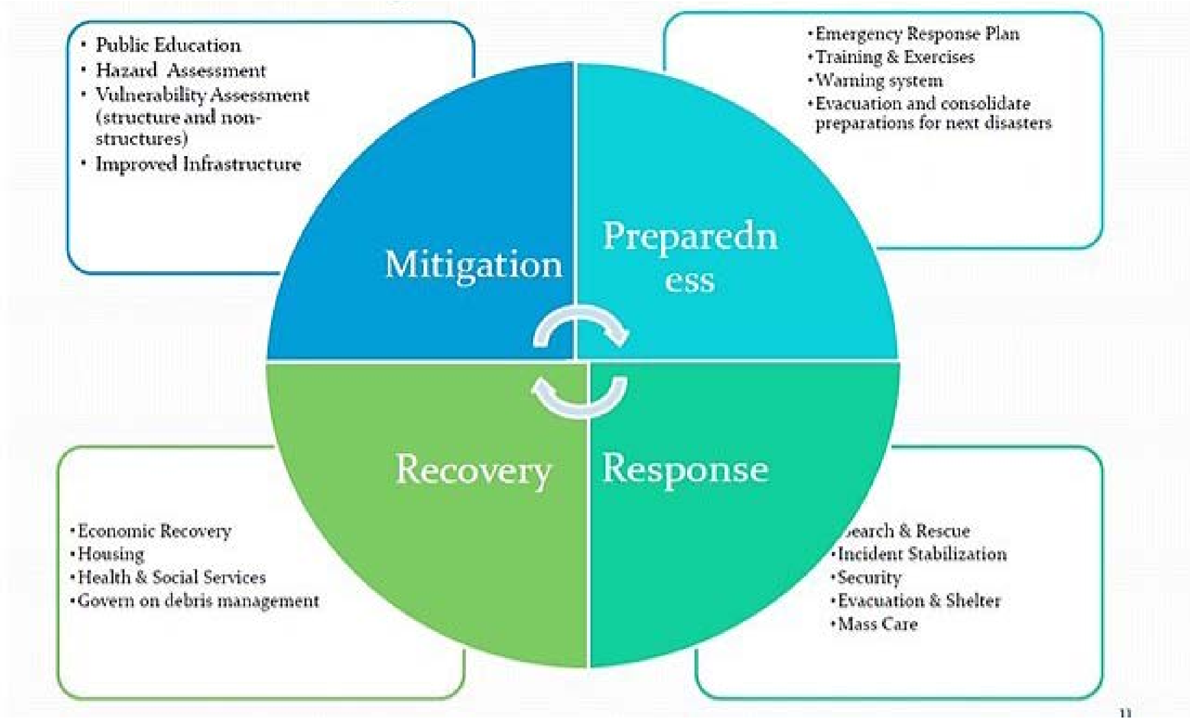
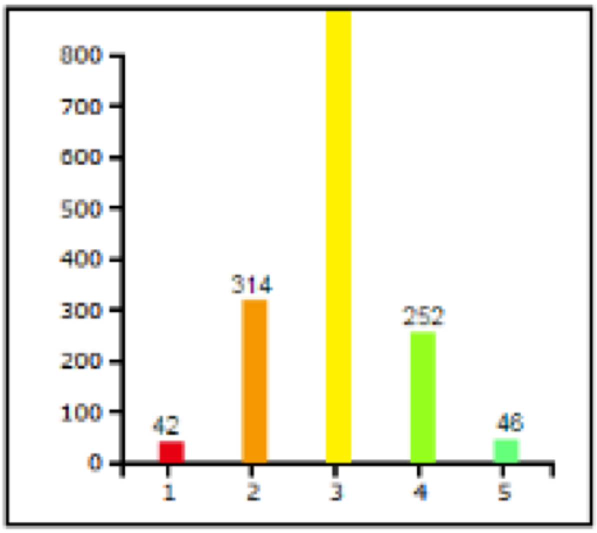
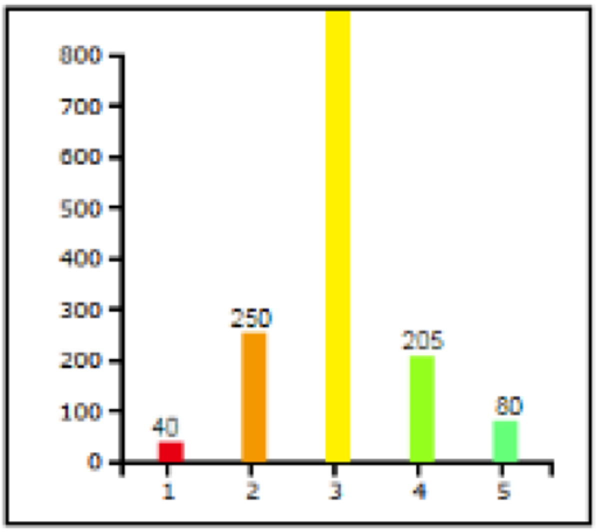


FIGURE 122. Prototype study for Lanmadaw Township (Tun Naing, 2018)



Number of damaged buildings



Number of damaged residential buildings

7.6 YANGON TECHNOLOGICAL UNIVERSITY AND UNIVERSITY OF TOKYO PROJECT

One of the key components of the YTU/ University of Tokyo project is the development of a disaster resilience system for Yangon.

The project integrates three components— software, hardware, and people's skills—with the goal of improving the DRR capacity of the city (Tun Naing, 2018). The system-level analysis is performed by conducting a vulnerability analysis and examining outcomes or consequences, and the required response in terms of process, schedule, and personnel. A prototype analysis for Lanmadaw Township has been completed (see Figure 122).

7.7 UNIVERSITY OF YANGON AND UNIVERSITY OF COLOGNE MULTIPLE RISKS MANAGEMENT

A new collaborative project between the University of Cologne (Germany) and the University of Yangon (UY) was in its inception phase at the time of writing.

The project is aimed at establishing a comprehensive DRM system for the city by developing (i) a research-based data bank for dissemination of information; and (ii) an awareness program to prevent loss of important documents in major events, mitigate economic loss, and maintain lifelines such as water, electricity, and health services (Kraas et al., 2019).

7.8 FIRST RESPONDERS

7.8.1 MEDICAL RESPONDERS

The Ministry of Health and Sports (MoHS) is responsible for medical response after natural disasters.

This includes (i) mobilization and development in affected sites, (ii) search and rescue, (iii) provision of medical services in temporary shelters, (iv) mobile clinic setup, and (v) patient transport to hospitals (Kyi, 2018). There are a number of healthcare facility types in the city. Currently, there are five general hospitals, including the 2,000-bed Yangon General Hospital; a number of specialist hospitals; six regional hospitals with 100 or more beds each; a number of private hospitals and clinics; and mobile hospitals. MoHS and the Myanmar Medical Association conduct training and simulation exercises as part of disaster preparedness. MoHS has also developed a hospital mass casualty plan as part of its emergency response (see Figure 123).

FIGURE 123. Hospital mass casualty plan (Kyi, 2018)

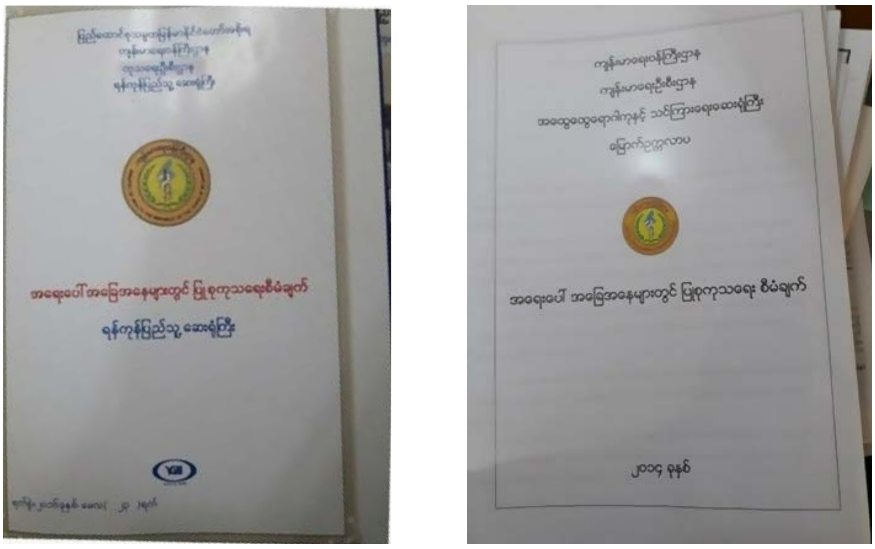
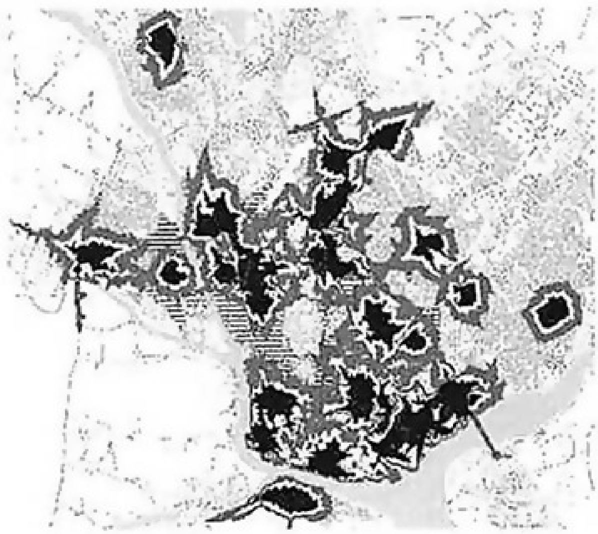


FIGURE 124. FSD emergency response control room

FIGURE 125. .Coverage time for emergency services at 6 PM (Bhatlacharya et al., 2018)

Hospitals reachable within 24 minutes



Firefighting coverage area

7.8.2 FIRE SERVICE RESPONDERS

There are 28 fire stations in the Yangon Region, excluding the stations in the suburbs.

Fire stations are divided into three grades: A, B, and C, with 21, 10, and eight firefighters, respectively (FSD, 2018). FSD is one of the agencies directly responsible for and participating in DRR and search and rescue efforts. The country uses three types of fire brigades: government, voluntary, and reserve. Members of the fire brigades are selected to conduct earthquake training and exercises and have been sent overseas for additional training (FSD, 2019). Figure 124 shows the FSD emergency response control room.

7.8.3 URBAN RESPONSE

A 2017 study identified the shortcomings of the current DRR systems and improvement areas to be considered for future urban planning.

Bhatlacharya et al. (2017) investigated the urban preparedness for emergency response in Yangon. The authors noted that people tend to arrive at hospitals based on their own plans; an approach that does not lend itself to centralized post-event (earthquake) response. Based on the existing road networks, assumed traffic speed, and location of hospitals and firefighting stations, the authors estimated response time at various times of the day. Figure 125 presents the simulated DRR coverage for medical and firefighting services at 6 PM.

7.9 BUILDING STRENGTHENING

As part of DRR, YCDC's earthquake response plan is aimed at strenghtening existing buildings.

An upcoming WB/YCDC project focuses on safer public facilities and critical infrastructure (Win, 2018b). For public facilities, two large market sites, two lifeline stations, and a reservoir intake building will be strengthened. For critical infrastructure, risk assessment will be undertaken for reservoirs and water supply networks. The project's objectives are not only to strengthen the critical built environment but also to assist in knowledge transfer and local technical capacity building. A 2017 VA study indicated that public buildings are at significant risk from earthquakes, and a large number of casualties for the public buildings for the lifeline buildings could be expected in the event of a major earthquake, as well as significant downtime (Miyamoto International, 2017). These buildings are therefore considered a priority for structural strengthening.

7.10 DISCUSSION

7.10.1 DEVELOPMENT OF DISASTER RISK MANAGEMENT

DRR and DRM are critical components of a city's resilience.

Yangon is vulnerable to a number of natural hazards, and unprepared to respond to such events. The implementation of a robust DRM program will have a significant beneficial effect on the community.

DRM comprises mitigation, preparedness, response, and recovery; VA can be used to enhance each of these four components. However, mitigation is the most cost-effective and functional approach to addressing risk and, as such, is emphasized in this report. Mitigation can include the strengthening of existing buildings; land use, and zonation to decrease the risk; and robust regulatory programs that emphasize code compliance and construction inspection.

7.10.2 RISK PERCEPTION

Risk perception is a key component in the development of a DRM program because people's perceptions can impact the success of program implementation.

Surveys on risk perception in two townships showed that the likelihood of natural disasters occurring in the city was generally deemed to be low. Furthermore, the impacts of natural disasters are not perceived as serious. Respondents also reported not having a clear understanding of mitigation actions. These observations highlight the importance of incorporating public education on natural disasters as part of the overall DRM program.

7.10.3 DISASTER RISK REDUCTION

A robust disaster risk reduction can expedite recovery in the event of major natural disasters.

The MCCDDM project was undertaken to support DMTC. One of the key functions of the project was to train the trainers (instructors) in DRM. This approach has been used successfully in natural hazard-prone countries and serves as a means of knowledge transfer and local technical capacity building.

- Cyclone Nargis called attention to the fact that natural hazards do occur and, when the country is unprepared, could have devastating consequences. The development of a national program to assess and document natural risk and to prepare a response plan will help to reduce the impact of future disasters.
- The development and implementation of a national disaster resilience program is a key step in reducing the vulnerability of Yangon and the country to natural hazards. A key component of a successful program is media outreach to educate citizens about the risk and how to respond in the event of a disaster.
- Natural hazards pose risks to humans, the built environment, and the economy. In many instances, past events have resulted in business interruptions that adversely impacted companies and the entire economy. The participation of the private sector as a partner in DRR is therefore critical.
- YCDC is working on the implementation of a multifaceted seismic DRR platform addressing preparedness, mitigation, response, and recovery. Similar programs have been successfully implemented in other major cities worldwide that are at risk from natural hazard. Once implemented, such platforms will enhance the resilience of the city and reduce the human and financial costs of major earthquakes.
- The comprehensive SATREPS project between YTU and the University of Tokyo intends to address several aspects of natural hazard venerability in Yangon. One important component is the development of DRR parameters and protocols. Using site hazard, exposure, and building or infrastructure fragility, DSs can be established. Based on damage, various outcome parameters are then extracted. The result is aggregated and used to compute post-disaster response parameters such as workforce, process, and schedule. This type of tool will enable YCDC to implement a robust DRM and facilitate resource allocation for future events.
- The multi-hazard preparedness joint project between the University of Cologne and UY will focus on Yangon and look at collecting and archiving research reports, mitigating losses during major events. This work will contribute significantly to the DRR in the city.

7.10.4 FIRST RESPONDERS

Medical professionals and firefighters are the first line of defense in the event of natural hazards and, as such, a key constituent in the development of a successful DRR program.

Both groups conduct training and exercises to prepare for emergency response. The medical team has developed a mass casualty response similar to protocols used in other risk-prone countries.

The geographical location of hospitals and firefighting stations can be used in urban planning to improve road conditions and connectivity. This, in turn, can reduce response time and increase the coverage area for first responders.

7.10.5 REDUCTION OF VULNERABILITY

Several steps can be taken to reduce vulnerability in the city.

Examples include:

- Improving the built environment by strengthening existing buildings and assuring that the new buildings are designed and constructed according to the building code requirements.
- Providing knowledge transfer and technical capacity building for YCDC engineers.
- As part of zoning and land use, restricting developments in the most vulnerable areas. This topic is discussed in the next chapter.

8. Laws and regulations

8.1 INTRODUCTION

The development of infrastructure in a resilient city or community is highly dependent on the underlying laws and regulations.

As discussed in the previous sections, Yangon is vulnerable to earthquakes, cyclones, floods, and urban fires. A robust damage risk program can be used to prepare for these events. However, impact can also be mitigated through the application of proper laws and regulations. For example, natural hazard vulnerability can be reduced by ensuring that (i) the building code meets international standards[23] and is enforceable; (ii) construction procedures are based on international standards and include good quality control, (iii) design engineers are licensed by the Myanmar Engineering Council (MEngC); and (iv) structural documents are reviewed during the permitting process, and on-site inspections are performed. Similarly, proper zonation and a development plan that clearly identifies vulnerable zones (such as liquefiable ground that requires soil improvement or deep foundation) and protected areas (such as river banks to mitigate flooding) would reduce the vulnerability of the built environment. These topics are discussed in this section.

8.2 MYANMAR NATIONAL BUILDING CODE 2016

8.2.1 GENERAL

MNBC 2016 has been developed as a revision of the 2012 edition of the national building code.

The 2016 code is mainly based on ASCE 7-05 (ASCE, 2006), various ASTM standards, and regulations and standards from other countries, adapted to Myanmar's construction. MNBC 2016 consists of seven parts (see Table 32) and was developed by MES, AMA, representatives from the construction industry, and other stakeholders. Working groups were formed to address specific components of the code. MNBC is intended for new constructions and not for the evaluation of existing buildings.

Parts of the code relevant to the scope of this report are presented in the following sections.

23. MNBC 2016 meets international standards.

TABLE 33. Parts of the code relevant to the scope of this report are presented in the following sections.

PART	DESCRIPTION
1	Planning, environment, administration, and legislation
2	Architecture and urban design (including fire resistance)
3	Structural design (based on ASCE 7-05)
3.3	Wind design
3.4	Seismic design
3.5	Concrete (based on ACI 318)
3.6	Steel (based on AISC 2005)
3.7	Masonry (based on ACI 350)
4	Soil and foundations
5	Building services
5A	Lighting
5B	Electrical and allied installations
5C	Installation of lifts and escalators
5D	Water supply, drainage, and sanitation
6	Building materials
7	Construction practices and safety

8.2.2 JURISDICTION AND COMPLIANCE

Part 1 of the code establishes the legal framework for the application of the code and the authority having jurisdiction for construction projects.

Part 1.1 states that the code shall apply to all buildings covered in the code. Part 1.2 establishes that an authority shall be created to enforce the code provisions and conduct inspections and describes the mechanism to address violations, including issuing stop work orders. Part 1.3 discusses the permitting and zoning requirements with which all buildings shall comply.

8.2.3 STRUCTURAL DESIGN REQUIREMENTS

Parts 3 and 4 detail building design loading parameters.

The load and load combinations closely follow the procedures specified by ASCE 7-05:

WIND DESIGN: for Yangon, the basic wind speed (3-sec gust) is listed as 100 mph, and importance factors are assigned based on the building importance factor. The design forces from wind loading are then computed, and provisions are made for wind uplift forces acting on the roof.

SEISMIC DESIGN: for Yangon, Sa and S1 are listed as 0.77 g and 0.31 g, respectively. These are based on rock sites and need to be amplified for site conditions, which are 1.2 and 1.8 for site class D (a common site in Yangon), resulting in Sa and S1 design spectral accelerations of 0.62 g, and 0.37 g, respectively. This indicates moderately high seismicity for the city and places Yangon in seismic design category D, a category for which the most stringent seismic design and detailing requirements would apply. Alternatively, the engineers can use seismic and soil class design maps to compute the seismic demand for specific sites. The code provides details on various types of building framing and height limitations for different construction. There are two key provisions for seismic design mandated in the code; the lack of compliance with these has led to many failures in past earthquakes. They are: (i) requirement for a complete load path to transfer the forces from floors to the ground and (ii) requirements for design of out-of-plane forces for walls and anchorage of walls.

CONCRETE DESIGN: this section details the requirements for minimum compressive strength of concrete, mixing, and sampling.

MASONRY DESIGN: this section details the requirements for minimum compressive strength of masonry, mixing, and sampling.

CONSTRUCTION PHASE: this part lists the provisions for building construction: (i) access for firefighting during construction; (ii) quality management, including quality of material; (iii) testing; (iv) inspection; and (v) safety.

FIRE RESISTANCE DESIGN: the code includes the following provisions: (i) provide adequate egress for fire hazard; (ii) provide smoke barriers for health care facilities; (iii) automatic sprinkler systems for high-rise buildings, including number of risers, system design, water supply for fire pumps, and emergency system detection alarm; (iv) specify different types based on applicability of one-hour fire-resistive construction; (v) provide minimum thickness of concrete members for fire protection; (vi) construct all elements of a structure in compliance with the appropriate fire resistance requirements; and (vii) fire-retardant treatment for bamboo.

FLOOD DESIGN: the code requires that flood loading be considered in the building design, when applicable, and that the exterior walls extending below the flood design elevation be resistant to water damage.

8.3 CONSTRUCTION LAW

The Construction Industry Development Board (CIDB) law has been drafted with assistance from Singaporean and Malaysian CIDBs and submitted to the parliament for approval.

As part of the development process, the Ministry of Construction (MOC) sent staff members to Malaysia and Singapore for a course related to project management, safety, quality control, and fire protection (Myanmar Times, 2018a). The CIDB will be a third-party organization comprising engineers and other experts in the field. The laws and regulations will also include a minimum standard for materials used in construction.

8.4 CONDOMINIUM LAW

The Condominium Law (Myanmar Law Library, 2019; Online Burma/Myanmar Library, 2019) was enacted in 2016. The Condominium Rules were passed by MOC in 2017 to clarify the Law, which is intended to streamline the construction process and encourage foreign investment.

Key requirements of the Law are as follows:

- A building of six or more stories and registered under the Condominium Law.
- A land area of 200,000 ft2 or more.
- Individual owners holding a condominium ownership certificate.
- Foreign ownership up to 40 percent.
- Presale permitted only after at least 30 percent of foundation work completed.
- A management board to supervise maintenance and resolve disputes.

The requirement for ongoing maintenance can facilitate detection of building deterioration, including structural, at earlier stages.

8.5 MENGC ENGINEERING LICENSING AND REGISTRATION

8.5.1 LICENSING REQUIREMENT

Engineering licensure requirements are implemented in many countries to ensure that buildings are designed by competent engineers.

In Myanmar, engineering licenses are issued by MEngC. Table 33 presents the different type of licensures available and requirements to become a licensed engineer (MEngC, 2013). EDB issues a separate license for engineers working on building construction in Yangon.

MEngC also provides clauses defining the scope of activities for licensees. For example, clause 37 specifies the requirements for holding a license to practice:

> *No one shall perform any engineering work and technological work, which are specified as being dangerous to the public by a rule enacted under this law, without having received a registration certificate issued by the council, except for engineers appointed in a government department or an organization in the performance of their duties.*

TABLE 34. Requirements for various engineering classification (MEngC, 2013)

TITLE	COMPONENTS	REQUIREMENTS	ENGINEER OF RECORD LIMITATIONS
Bachelor of Engineering (BE)	Academic	Holder of a Bachelor of Engineering degree from a MEngC-accredited university (e.g., YTU)	Cannot be in responsible charge
Registered Engineer (RE)	Background Experiences Examination	BE Same as Engineer	Residential construction
Registered Senior Engineer (RSE)	Background Experiences Examination	RE Present competency as part of past experience	Buildings of up to eight stories; including seismic design
Professional Engineer (PE)	Background Experiences Examination	RSE Professional experiences and competency Report showing projects and work performed Professional presentation on projects and achievements	No limitations

It is not clear to what extent the law is being enforced. In addition, there are currently no requirements for professional insurance that could provide some safeguard in the event of negligence. According to the Myanmar Times (2019), there are 500 RSEs and 350 PEs in the country. However, many engineers practice without registration.

8.6 PERMITTING, CONSTRUCTION INSPECTION, AND CODE COMPLIANCE

8.6.1 PERMITTING PROCESS

A 14-step procedure is followed to construct a building in Yangon (WB, 2017), as summarized in Table 34. YCDC EDB is involved in the office review of building submittal plan, field inspection during construction, and issuing the Building Completion Certificates (BCC) (Myanmar Times, 2018b)[24]. EDB has the authority to stop a construction if not compliant with the plans submitted.

The structural permit review process depends on the number of stories in a new construction, as listed in Table 35 (Oxford Business Group, 2016).

The permit process can take from several months to about a year for larger projects. In 2015, an online application process was introduced to simplify and expedite the process. YCDC is partnering with the International Finance Corporation (IFC) to streamline the construction permitting process and support regulatory reforms. The project goal is to develop an efficient and transparent online permitting system (Myanmar Business Today, 2018).

24. BCCs are issued by the YCDC Engineering Department (Buildings).

TABLE 35. Procedure for building construction (WB, 2017)

STEP	PROCEDURE	COMMENT
1	Obtain land title certificate	
2	Consent from neighbors	
3	Recommendation letter from ward	
4	Design compliance with urban and building standards (prepared by a licensed engineer)	YCDC
5	Construction permit	YCDC EDB review
6	Initial inspection, general land inspection	YCDC EDB soil tests required for buildings of three or more stories
7	Foundation inspection	YCDC EDB construction inspection
8	Floor inspection	YCDC EDB construction inspection
9	Roof inspection	YCDC EDB construction inspection
10	Request BCC	
11	BCC inspection	YCDC EDB visit to the site to check if built per plans
12	BCC	YCDC EDB issues if there are no problems
13	Well excavation permit	YCDC
14	Drill for water	

TABLE 36. Permit review process for buildings of various number of stories (Oxford Business Group, 2016)

STORIES	REVIEW BY	NOTES
1–3	YCDC	Voluntary compliance with MNBC
3–8	YCDC	Compliance with MNBC
8.5–12	High-Rise Inspection Committee	Compliance with MNBC
12.5 and more	Committee for Quality Control of High-Rise Building Construction Projects (CQHP)	Compliance with MNBC Regulatory approval from other agencies

8.6.2 HIGH-RISE BUILDINGS

For tall buildings, CQHP conducted design checks, including structural, electrical, and mechanical.

Some of the key structural requirements include (CQHP, 2017a):

- Requirements for geotechnical report, including pile load tests, soil bearing capacity, and liquefaction analysis.
- Structural plans and drawings signed and stamped by structural PE.
- Wind loads based on the code (Yangon: 100 mph).
- Seismic loads based on the code (Yangon: zone IIB).
- Requirements for three-dimensional analysis.

For fire safety, CQHP refers to the guidelines and regulations set by the fire department.

The reviewers then perform checks to ensure adequacy of design for architectural, structural, electrical, and mechanical compliance. For example, structural checks include (CQHP, 2017b):

- Material properties.
- Structural system.
- Base shear calculations (wind and seismic).
- Structural design.
- Foundation design.
- Liquefaction analysis results.
- Structural drawings, including plans, sections, members, and schedule.

8.6.3 CONSTRUCTION QUALITY CONTROL

One major factor affecting construction quality is the shortage of good-quality material.

The country imports a large portion of its concrete and steel. The material's quality, especially for reinforcement, does not always meet international standards, as discussed in section 4.2.3. There is also a shortage of skilled construction workers. To help with upskilling, UN-Habitat and MES conducted training for carpenters and masons (MIMU, 2017). Almost 500 participants were trained to various carpenter or mason skill levels.

8.7 ZONATION AND PLANNED URBAN DEVELOPMENT

8.7.1 GENERAL

As discussed in section 3.5, Yangon is a dynamic city that is experiencing rapid population growth.

To streamline urban growth and accommodate the incoming population, the City Planning and Land Administration Department of YCDC has been working with a number of agencies to develop city planning and growth programs. Some of the activities are summarized in this section.

8.7.2 LAND USE AND ZONING PLAN

YCDC has established restrictions regarding building height in specific cases.

For example, height limits have been set for areas close to heritage sites to preserve the characteristics of the heritage buildings.

As part of a 2017 project, YCDC and the French Development Agency (AFD) conducted zoning and land use studies in Yangon (AFD, 2017).

The project scope involved three components: (i) conducting field surveys and preparing land use of Yangon in as-is condition; (ii) developing the aims of the zoning plan; and (iii) preparing graphical documentation for each township. One of the key objectives of the project was the preservation of riverbanks for flood control. The Hlaing Township was selected for the pilot study, and field surveys were conducted to document population density and built environment. In addition, aerial imagery from 2012 and 2016 was used to examine the scope of change in the township (see Figure 126 for an example). Based on surveys and aerial mapping, the authors determined the population density for various wards. This township has a dense but non-uniform population distribution. A review of 2012 and 2016 imagery also showed that the construction is changing from detached houses to mid-rise buildings on small plots of land.

The authors recommend that the zoning plan address the following:

- Consider the acceptable population density for each part of the township.
- Establish the kind of buildings permitted for construction.
- Ensure building design allows occupancy in times of natural disasters.
- Provide means for transportation, including public transit.
- Include provisions for green and open space.
- Establish written regulations to allow construction control during permit issuance.

The project also noted that the lack of a built environment database presented a hindrance.

8.7.3 URBAN DEVELOPMENT

A 2016 report (United Nations, 2016) outlines the urban development of Myanmar and Yangon.

Key findings from the report include:

- Yangon, with nearly 70 percent urban population, has the highest urban rate in the country.
- For Yangon, internal migration accounts for over 80 percent of population growth from 2010 to 2014.
- Myanmar formulated a national urbanization policy to provide a general urbanization framework for the cities.
- In 2016, a National Land Use Policy was issued to address land ownership and use.
- The greater Yangon Vision 2040 was approved by the parliament of the Yangon Region.
- Approximately 10 percent of the population in Yangon lives in informal settlements. The city has been implementing an assessment and resettlement plan.

UN-Habitat sponsored the development of the Myanmar National Urban Policy Framework (MOC and UN-Habitat, 2017). The study found disorganized urban growth in both formal and informal settlements. The authors recommended upgrading existing informal settlements rather than undertaking resettlement programs.

UN-Habitat (2016a) investigated urban planning in Myanmar and recommended the development of a national policy and a capacity-building program. The report recommended policies that would encourage efficient development of the land and provide a variety of housing options. In particular, for growing cities such as Yangon, advance planning for the expected growth could be very beneficial. A step-by-step solution, including citywide analysis to identify city extensions, and the development of an urban pattern were recommended.

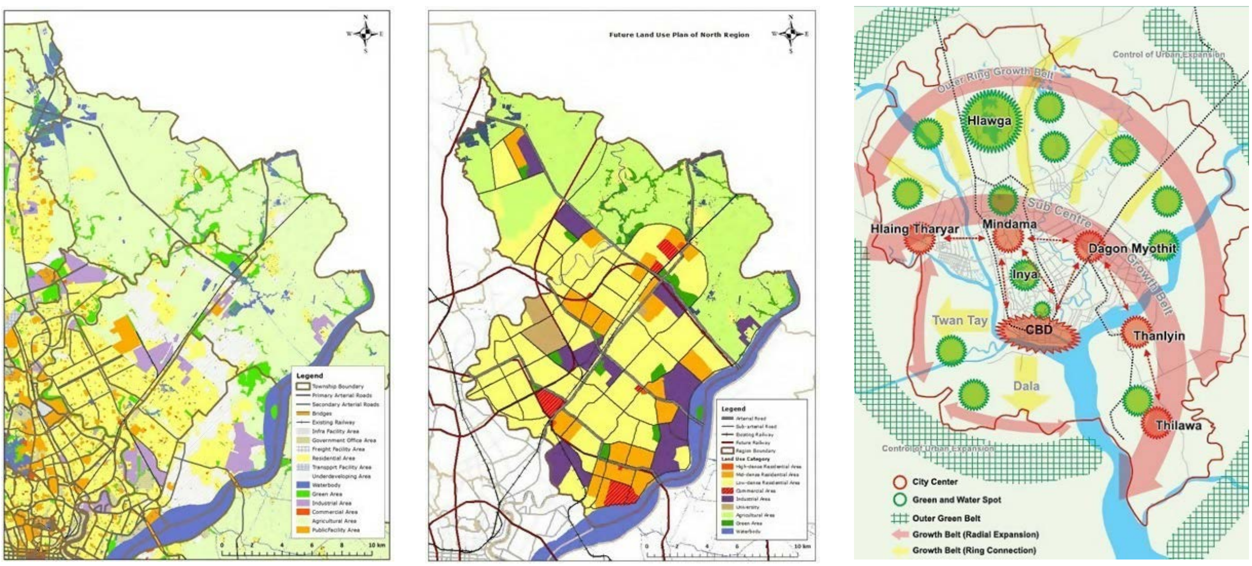
FIGURE 126. .Example of urban development in the township (AFD, 2017)

2012

2016

FIGURE 127. **Proposed height restrictions in the CBD (JICA, 2014)**

FIGURE 128. **Current and future urban structure for Yangon (JICA, 2014; YCDC, 2014)**



Current | Proposed | Future urban structure

Current and future built environment, northeast townships

8.7.4 YANGON VISION 2040

The Yangon Vision 2040 is a joint YCDC/JICA project.

It aims to (i) modernize utilities and roads; (ii) build new urban centers, including residential and commercial hub; and (iii) reduce the traffic congestion downtown.

As an initial step in the process, 10,000 households were surveyed to determine the existing conditions, and digital maps for the city were prepared based on Google Maps. Of the surveyed households, nearly 80 percent lived in detached houses, and 20 percent in collective housing (YCDC and JICA, 2013).

The project's study area considers Greater Yangon, which consists of the 33 townships in Yangon City and six peripheral townships in the Region to account for future growth. The study also identified the impact of natural hazards in Yangon and noted that earthquakes, cyclones, and floods pose a threat to the city (JICA, 2013). The project looked at housing, roadway, utilities, green space, and other factors as part of future development planning.

In a follow-up report (JICA, 2014), the results of case studies and capacity development planning were articulated, and detailed plans for pilot sites were developed. Working groups comprised of JICA, YCDC, MOC, YHT, AMA, and other stakeholders were formed to analyze land use and building heights. For the heritage zone in the Central Business District (CBD), the plan envisions only low- to mid-rise buildings to ensure preservation (see Figure 127). An example of the proposed development plan is shown in Figure 128 (JICA, 2014).

Next, a strategic plan was developed to address the main city development goals. The proposed urban structure comprises a CBD (downtown area) and a number of sub-centers connected by enhanced transport systems (see Figure 128) (YCDC, 2014). A land-use zoning plan was developed using the GIS data developed earlier, including control redevelopment (CBD and heritage zones), control urban (green zones), and proportion areas (suburbs and urban centers).

In 2017, an updated version of the plan was developed by JICA and submitted to YCDC (Myanmar Times, 2017). The new version included short-, medium-, and long-term plans to be adopted incrementally. The updates were due in part to the worsening of traffic in the city since the initial 2012 study, and aimed to take public transit into more detailed consideration. YCDC has been in discussions with JICA, the Korea International Cooperation Agency, AFD, and DFID to streamline the Yangon Vision 2040 master plan.

8.8 DISCUSSION

8.8.1 MYANMAR NATIONAL BUILDING CODE 2016

MNBC 2016 is a robust code that relies on international standards modified for hazard and construction in Myanmar.

The code addresses earthquake, wind, flood, and fire hazards. It contains mandatory language requiring permitting, compliance, and reinforcement and sets the legal basis for its enforcement. The code includes provisions for construction practices such as material quality control and construction inspection and sampling.

At the time of writing, MNBC 2016 has not yet been approved by the parliament. Accordingly, adherence to its provisions is not mandatory and depends on jurisdictions. The adaptation of the code as a legal binding document will improve structural safety in Yangon significantly.

8.8.2 CONSTRUCTION LAW

The establishment of the CIDB will be beneficial in reducing the vulnerability of the built environment in Yangon.

Key features of the Construction Law are the requirements for (i) compliance with international safety and quality control standards, including minimum standards for materials; and (ii) fire alarm systems and inspection. An improvement in quality control and materials used will lead to the construction of better and safer buildings, which are less vulnerable to natural hazards, while the requirements for fire protection and inspection will reduce the vulnerability of buildings to fire hazard.

8.8.3 CONDOMINIUM LAW

The Condominium Law permits ownership of buildings by foreigners and establishes a mandatory maintenance program. Foreign ownership could lead to better construction as investors would demand a safer return on their capital, while the maintenance program could result in better upkeep, including mitigating structural deterioration that could increase the vulnerability of a building to natural hazards.

8.8.4 ENGINEERING REGISTRATION AND PRACTICE

There are national and citywide requirements for licensing engineers.

However, not all practicing engineers hold a license. It is important to ensure that, as a minimum, the Engineer of Record responsible for a construction project is duly registered. The development of a professional engineering insurance program can facilitate wider implementation of licensing and registration requirements.

8.8.5 PERMIT AND INSPECTION PROCESS

For high-rise buildings, experts and experienced engineers review the structural plans and assess compliance with code provisions, including for natural hazards such as earthquakes.

However, for low-rise buildings, compliance is voluntary. Code provisions should be enforced uniformly for all buildings. The development of a transparent online permitting process is a positive step forward that will likely accelerate the process. However, the system needs to include adequate checks and reviews to ensure that the buildings are designed and constructed according to the national code and international standards.

Addressing low material quality and shortage of skilled labor is critical. With the establishment of the CIDB and more vigorous enforcement of MNBC 2016, it is expected that higher-quality materials will be used, and improvements in construction will lead to a reduction in building vulnerability. Training sessions offered by UN-Habitat and others are a key factor in improving the quality of construction by building workers' skills. In addition, skilled construction jobs are usually well-remunerated roles, which contributes to improving the local economy.

8.8.6 ZONATION AND LAND USE

To accommodate the expected growth in the city, a zoning plan is needed to establish how and where the growth is to take place and what type of construction is permitted at a given site.

An initial step in this process involves documenting the existing condition of the population and built environment in the townships through field surveys and analysis of aerial imagery. The resulting maps and data can then be used as part of land use development. These data are critical in developing the current and future exposure models for the city. Accordingly, maintaining a collaborative and accessible database, including GIS mapping, is critical. Finally, zonation can be used to reduce both exposure and vulnerability to natural hazards. For example, certain developments can be curtailed in areas of high hazard potential (exposure), or development at riverbanks can be restricted to mitigate flooding (vulnerability).

YC has ambitious development goals in its Yangon Vision 2040. To achieve these goals, national and regional urban growth planning is needed, and addressing the haphazard growth of both formal and informal settlements in the city is crucial. Efficient development of land, diversified housing, and upgrade of informal settlements are some of the features that can be included in the overall development policy. Given the vulnerability of the city to natural disasters, it is also fundamental to consider natural hazards, emergency response, and vulnerability mitigation when long-term master plans are developed and implemented.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9. Vulnerability Reduction: Building a Regulatory Platform

9.1 OVERVIEW

As discussed previously, a robust building regulatory system is a key component of DRM.

The lack of such system has contributed to the disproportionately higher adverse effects in the aftermath of natural disasters in developing countries compared to developed countries (see Table 36).

Several factors contribute to the higher number of casualties and injuries, the extent of damage to the built environment, the associated financial costs for restoration, and the delayed recovery time in developing countries:

- Lax enforcement of building code provisions or use of outdated building codes.
- Lack of zoning and development plans, leading to buildings being constructed in zones prone to hazards and with building framing not appropriate for a site.
- Construction issues, including a shortage of qualified and skilled construction workers, subpar quality of material, and inadequate construction quality control plans.
- Insufficient regulations regarding the practice of engineering, including licensing, certification, and knowledge.
- Issues with permitting and review processes, including the requirement for submittal and checking of plans and drawings.
- Issues with construction inspection, including compliance with design documents and stop work orders.
- Absence of liability for engineers and contractors for the submitted and completed products.

TABLE 37. .Comparison of natural disaster impacts on developing and developed countries

EVENT	INTENSITY	CASUALTIES
2015 Nepal earthquake	Mw 7.8	9,000
2010 Chile earthquake	Mw 8.8	525
2008 Cyclone Nargis	165 km/h	138,000
2018 Jebi Typhoon	195 km/h	17

Most of the factors listed relate to building regulations. To reduce the vulnerability of the city and increase its resilience, it is therefore important to review the existing process and implement measures to improve the building regulatory structure.

Although not part of the scope of this report, a brief discussion of the topic is included here to highlight its importance and its impact on community health, reduced vulnerability, and enhanced resilience.

9.2 BUILDING REGULATIONS

Building regulations are minimum standards established to ensure that buildings are designed and constructed in a manner that ensures safety (preserves life) for the people occupying them or affected by the structures.

As these regulations are minimum standards, the definition does not imply no damage. In fact, buildings designed and constructed according to the code are expected and have been damaged during significant natural hazards such as earthquakes, necessitating major repair and/or replacement. However, code-based design buildings have a low probability of collapse in major events and thus minimize human losses. Life preservation is a key consideration in the development of building codes. VAs and post-disaster surveys conducted by the authors have shown that fatality rates of 1 percent to percent can be expected for buildings that are not compliant with modern codes. This rate is reduced by a factor of 10 or more when design and construction meet the code provisions. This observation points to the importance of implementing a robust building regulatory system.

The development of such a system involves assessing the current system (including the current building code, permitting and review process, and enforcement) as part of the BRCA, followed by Building Regulations for Resilience.

9.3 RESILIENCE

Resilience can be defined as the capacity of a city or community to bounce back from a disaster.

In terms of cities and communities, resilience is usually measured in terms of casualties, financial costs and downtime, with the objective being to reduce all three dimensions. Figure 129 illustrates the concept of resilience for two communities experiencing the same natural hazard. The more resilient community:

- Would experience lower initial impact (deaths and financial losses).
- Would respond more quickly due to the development of the DRR platform.
- Would require a shorter time and less money to complete restoration.
- Would likely reach the same level of performance and services as prior to the natural hazard.

The application of resilience to structural engineering involves translating engineering quantities (e.g., forces and displacements) to socioeconomic metrics (e.g., casualties, downtime, and repair costs). One of the best-known tools for this task is the PEER triple integral methodology developed by Cornell and Porter as shown in Figure 130 (PEER, 2019b).

Based on facility information and design, probabilistic analysis is performed on natural hazard, structure, damage, and losses to produce an outcome that can be used by decision-makers and officials. Building regulations impact the first input parameter, namely location and design of the structure, and therefore affect all subsequent analyses and outcomes; herein lies the importance of implementing a robust system.

9.4 BUILDING REGULATIONS FOR RESILIENCE

GFDRR (2015) presents the concept of Building Regulations for Resilience for developing countries.

The report identifies a number of possible reasons why building regulations have not reduced disaster risk in developing countries, including:

- Ineffective land use.
- Weakness of building code administration.
- Insufficient legislative foundations.
- Unaffordability of costs associated with compliance.

The report identifies two key recommendations:

- Stop the expansion of risk in new settlements.
- Reduce risk in existing settlements.

To achieve these objectives, a four-component program is proposed:

- National-level legislation.
- Building code development.
- Local implementation.
- Knowledge sharing and measurement.

9.5 APPLICATION OF METHODOLOGY

During recent major natural hazards, it has been observed that buildings designed according to current modern codes have performed well and saved lives.

For example, recent earthquakes in California, Chile, and Japan have registered a significant decrease in the number of casualties compared to similar past events. In Myanmar, MNBC 2016 is a robust code developed according to internationally recognized standards. The engineering, real estate, and construction professions, as well as government officials, are also cognizant of the importance of compliance to the building code and other regulatory provisions. Successful examples from other developing countries can be used as a road map in establishing a robust regulatory system, resulting in decreased vulnerability to natural hazards and enhanced livability and resilience for the city.

FIGURE 129. Resilience concept

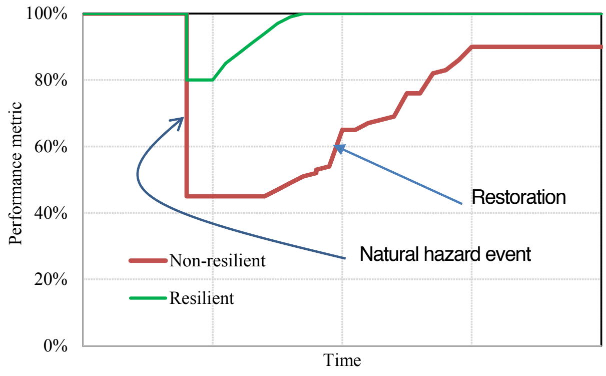
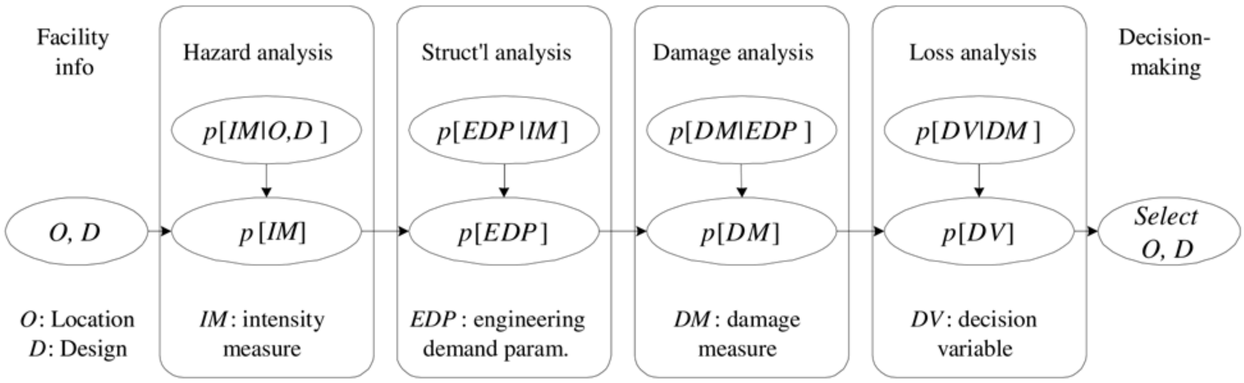


FIGURE 130. PEER decision-making platform (PEER, 2019a)




JUNCTION CITY

10. Summary and conclusions

10.1 SUMMARY

10.1.1 HAZARD ENVIRONMENT

Considerable efforts have been undertaken by a number of organizations to characterize the earthquake, cyclone, flood, and urban fire hazard in Yangon.

A review of findings showed consistent results. In particular, the following is noted:

- The city is vulnerable to these and other chronic hazards.
- Some areas near the river have soft soil due to landfills, and there are townships susceptible to liquefaction. Overall, the earthquake risk for the city is moderately high.
- Flooding is common in the city. The two main types of floods in Yangon are (i) a combination of riverine floods and flooding due to cyclone and storm surge; and (ii) localized floods, including urban floods.
- Several urban fires occur annually in Yangon. Building construction type, negligence, improper use or storage of cooking fuel, and inadequate electrical connections contribute to urban fire. Informal settlements are particularly vulnerable to this hazard.

10.1.2 EXPOSURE TO HAZARD

Data for built environment and population exposure are rather limited and fragmented.

In recent years, several major projects have been launched to obtain more detailed data and statistically organize the information. State-of-the-art technologies such as LiDAR, satellite imagery, and digital images are being utilized.

Slightly over 2,900 construction permits were issued in 2017–2018. A large number of buildings are eight stories or less, although the city houses several high-rise buildings. The main building types in the city are RC, BN, masonry, and wood.

10.1.3 BUILDING CONSTRUCTION AND FRAGILITY

A large number of existing buildings in the city were constructed using unreinforced masonry bearing walls, one of the building types most vulnerable to earthquakes.

Field surveys of newer construction have shown that the concrete used is of low strength, and the reinforcement is undersized. BN construction performed poorly during the 2012 earthquake in Myanmar.

Cyclone and flood fragility assessments are not yet complete for the city.

In the event of a design level earthquake in YC, it is likely that ensuing fires will occur. Due to congested housing, small separation between buildings, and lack of yards, the fire can spread rapidly.

10.1.4 ASSESSMENT METHODOLOGY

RVS of a number of townships has been completed for earthquake assessment.

Overall, several thousand buildings have been visited and assessed. Approximately 30 percent of buildings were found to require additional investigation or strengthening. Numerical analysis also predicted similar response, i.e., the buildings investigated were vulnerable to damage in major earthquakes.

Cyclone and flood assessments are not yet complete for the city.

Building vulnerability to urban fire is related to construction type and preventive measures. Fire-resistant structures, sprinklers, and alarm systems can reduce vulnerability significantly.

10.1.5 DAMAGE ASSESSMENT

The development of a post-event damage assessment program is a key step toward recovery.

Currently, such platforms are not common in Yangon, although the fire department collects some data related to cause and location of fires.

10.1.6 DISASTER RISK MANAGEMENT

VA can be used to enhance each of the four components of DRM: mitigation, preparedness, response, and recovery. Surveys of people's perceptions in two townships showed that they considered the likelihood of natural disasters occurring in the city to be low. Furthermore, the impacts of natural disasters were not perceived as serious. Various programs related to preparation and response have been implemented in the city, with the fire department and medical teams participating in training and rescue exercises. YCDC is working on the implementation of a multifaceted seismic DRM.

10.1.7 LAWS AND REGULATIONS

MNBC 2016 is a robust code that relies on international standards modified for hazard and construction in Myanmar.

The code addresses earthquake, wind, flood, and fire hazards. It contains mandatory language requiring permitting, compliance, and reinforcement and sets the legal basis for its enforcement. The code includes provisions for construction practices such as material quality control and construction inspection and sampling.

The development of a transparent online permitting process is a positive step forward that will likely accelerate the process. However, the system needs to include adequate checks and reviews to ensure that the buildings are designed and constructed according to the national code and international standards.

10.2 CONCLUSIONS

The built environment in Yangon is vulnerable to earthquake, cyclone, flood, and urban fire; mitigating the impact of these natural hazards is crucial.

- Wood and bamboo construction accounts for nearly 55 percent of all buildings. These buildings would perform well in earthquakes but are vulnerable to cyclone, flood, and urban fire.
- Concrete and masonry account for 35 percent of all buildings, and masonry and brick noggin buildings have performed poorly in past earthquakes. Similarly, concrete buildings that are not designed properly do not perform well in earthquakes. Low concrete strength and undersized reinforcements contribute to the vulnerability of newer RC buildings. However, if properly designed and constructed, these buildings would perform well in earthquakes and cyclones.
- Fire in the aftermath of an earthquake can be prevented or slowed by using gas shutoff valves, ensuring buildings are fire-resistant, and providing sufficient firefighting trucks, equipment, and water supply.
- RVS has been used in a number of townships to assess the vulnerability of buildings to earthquakes. RVS is an effective tool that can provide broad and rapid information about a building. Similar tools are also available for other hazards and can be used to quantify a building's performance.
- Damage assessment data can be used to identify and classify the types and locations of buildings that are vulnerable to a given hazard. Such data can then be used by city planners and engineers to quickly identify buildings that are safe to reoccupy and plan for future mitigation.
- Mitigation is the most cost-effective and functional approach to address risk; it can comprise strengthening the existing built environment; mandatory implementation of robust building codes; and improved construction quality management.
- In Yangon, the results of a citizen survey on their perception of risk were found to be in disagreement with empirical data for both likelihood and impact. This shows the importance of public education regarding natural disasters; incorporating such education as part of the overall DRM program and planning.
- DRM and DRR programs have been successfully implemented in other major cities worldwide that are at risk from natural hazards. Once implemented, such platforms will enhance the resilience of the city and reduce human and financial costs due to major earthquakes.
- The establishment of the CIDB, including provisions for quality control and material use, will be beneficial in reducing the vulnerability of the built environment in Yangon. Additional training of workers such as carpenters and masons will lead to the construction of better buildings.
- Given the vulnerability of the city to natural disasters, it is also fundamental to consider natural hazards, emergency response, and vulnerability mitigation when long-term master plans are developed and implemented.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