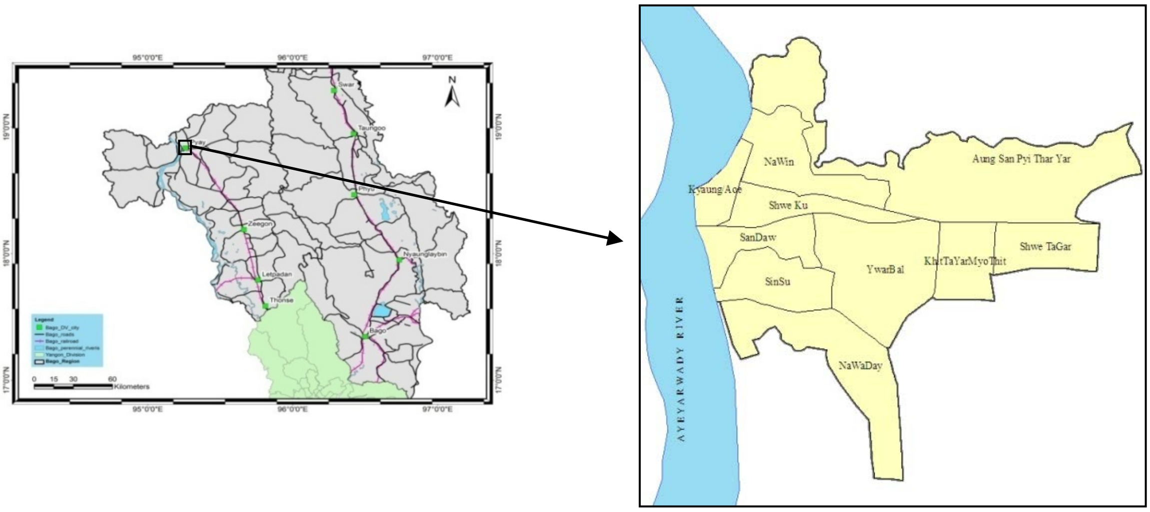
ENHANCING AND DEVELOPING SEISMIC RISK ASSESSMENT FOR PYAY CITY OF MYANMAR



Safer Costal and Urban Communities through Inclusive Disaster Risk Reduction in Myanmar

Project Funded by DIPECHO

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CONTENT

EXECUTIVE SUMMARY

Myanmar is prone to different intensities of earthquakes as it is located on one of the two main prominent earthquake belts of the world with a complex seismotectonic processes (Le Dain et al., 1984). At least nineteen earthquakes of $M_s > 7$ have occurred in the region. The great Arakan earthquake of 1762 caused extensive changes in the level of the Myanmar (Burma) coast. The 1878 earthquake caused uplift of 6 m on the west coast of Ramree Island, while another island seems to have disappeared.

Among the active fault regions Taungoo – Bago, and Sagaing – Tagaung (Zone V) did not experience any major seismic activity over the past half a century. According to Probabilistic Seismic Hazard Map of Myanmar (2012), there is potential for earthquake along Sagaing Fault. In an around the Pyay area, significant faults are observed and those are well known, Pyay Thrust Fault, West Bago Yoma Fault, Gwegyo Thrust Fault and Sagaing Fault (U Soe Thura Tun, Seismic Hazard Assessment, 2015). Pyay Thrust Fault is located in the western part of Pyay City. If earthquake happens around Pyay City, there may be increasing potential damage to the community and also to the building. There is more population in Pyay area and the city is developing rapidly. Therefore, it is considered essential to take Seismic Hazard Assessment. The purpose of this risk assessment is to acquire the vulnerability of buildings and urban structures so that the preparedness measures and Pyay city development plans can be incorporated accordingly.

Seismic risk assessment was done with field survey of the building inventory and demographic data collection. Seismic hazard assessment work from Myanmar Geo-science Society was referenced in assigning seismic source parameters. Scenario earthquake of Magnitude M7.4 in Padaung Segment of Pyay Thrust Fault is considered for the risk assessment work.

According to the demographic data and building inventory, Pyay city is 304.41 square mile (194,820 acre) wide comprising of 10 wards. Population is around 113,620 with a female and male ratio of more than one in every ward, meaning there are more female than male population. Ywar Bal Ward has the highest number of population among other wards in Pyay. However, Khit Ta Yar Myo Thit Ward, which is industrial zone area, is the most densely populated ward and it is also the highest building density ward. Most of the buildings in Pyay City is brick nogging (Unreinforced Masonry Bearing Walls with Wood Diaphragms

Building - RM Building Type). There are total 31 schools in project area of Pyay city. Among 8 nos. of total hospitals, only one is government and the rest are private hospitals.

HAZUS methodology is applied in seismic risk assessment with maximum probable earthquake scenario of Magnitude 7.4 in Pyay Thrust on Padaung Segment. The assessment results can be found in map format of Direct Earthquake Damage and Economic Losses (shown in Appendix - B). Damages are expressed in three categories; Direct Earthquake Damage, Induced Earthquake Damage, Casualties and Building Related Economic Loss. For Direct Earthquake Damage for buildings are enumerated with four stages; slight, moderate, extensive, and complete damage.

Under M7.4 maximum probable earthquake scenario, it is estimated that about 20,890 buildings, which is over 97% of the total number of buildings in Pyay City will be at least moderately damaged. HAZUS estimated that 17,451 buildings will be damaged beyond repair. On that day of the earthquake, it is estimated that 100% of essential facilities that provide services to public are available for use by the public. Damage stages by ward levels are shown in Appendix – B. For induced earthquake damage, it is mentioned with debris generation. According to analysis, it is estimated that there is no generated debris at the time of the scenario earthquake. Total building related economic loss is estimated to be 1,718,360 millions kyat, 52% of the estimated losses were related to the business interruption of Pyay City. The largest loss was sustained by the residential occupancies which made up over 68% of the total loss.

Seismic risk assessment of Pyay City is performed with the current building inventory and demographic information analyzing based on the maximum probable scenario earthquake. Stakeholders can include the assessment results into their future city development plans. Preparedness measures for essential facilities such as for life saving, fire fighting and transportation can be decided. The results are also useful for communities, understanding the vulnerability of the area where they live in, to understand how to behave in case of an earthquake.

HAZUS tool used in this seismic risk assessment work is the estimation of the damage during the scenario earthquake that is defined by the user. Transportation such as road and streets are not included in this analysis. Stakeholders can think of revising the inventory data covering the current condition of the city.

1. INTRODUCTION

1.1 Background

While the main active tectonics characteristics are the subduction zone of Indian plate and Burma (Myanmar) plate in the West of Myanmar and the collision zone of Indian plate and Eurasia plate in the North West there are several fault lines traversing across the country. The Sagaing fault is the most prominent active fault in Myanmar which extends from north of Lake Indawgyi southward along the Ayeyarwady River north of Mandalay and along the eastern margin of the BagoYoma to the Andaman Sea (Hazard Profile of Myanmar, Sato, 2009). The Deterministic Seismic Hazard Zonation Map of Myanmar developed in 2005, classifies Myanmar into five seismic zones, Zone I (Low Zone), Zone II (Moderate Zone), Zone III (Strong Zone), Zone IV (Severe Zone), and Zone V (Destructive Zone). Tarlay earthquake occurred in Shan State in 2011 highlighted the vulnerability of building stock in Myanmar. Considering the majority of the building stock in both urban and rural areas comprising of non engineered structures such as made of wood, brick, reinforced cement concrete there is an increasing concern on the potential damage to major urban areas such as Yangon, Bago, Taungoo and Sagaing, Pyay, Meikhtila, and Taunggyi along the Sagaing fault.

While Disaster Risk Reduction is a nascent stage, efforts are underway to reduce the vulnerabilities through specific interventions such as multi-hazard risk assessment. In this regard, it has been proposed by UN-HABITAT to carry out earthquake related risk assessments in three cities of Myanmar: Sagaing, Bago, and Taungoo Cities in collaboration with Relief and Resettlement Department, Myanmar Engineering Society, Myanmar Geo-science Society and Myanmar Earthquake Committee with the support from Norway Ministry of Foreign Affairs (NMFA) and ECHO (DIPECHO VIII) since 2012.

Based on the developed risk assessment tools of three cities, Pyay is also considered as the priority for next Earthquake Risk Assessment (DIPECHO IX) project. Pyay earthquake that happened on 24th August 1858 causes damages of houses and Pagodas at Pyay City. Pyay have a population of more than 113620 people as per survey results (2015) and the city is developing rapidly with the construction of mid-rise buildings. Therefore, it is decided to make earthquake risk assessment in Pyay City. The results will be in useful in developing comprehensive risk reduction programs addressing the specific vulnerabilities in the city. The risk assessment will guide to future development in the cities along with UN-Habitat's Myanmar Comprehensive Disaster Risk Reduction Programme and also with broader DRR activities and those of Government.

1.2 Objectives and Scope of the Project

The main intension of the project is to develop the knowledge and resources that can be used in seismic risks mitigation decisions. The specific objectives are as follows:

1. To acquire the vulnerability of buildings and urban structures of Pyay City
2. To carry out seismic risk assessment
3. To incorporate the results into preparedness programmes and urban development plans
4. To apply risk assessment and prevention programmes for further development of Pyay City

Using Seismic Hazard Assessment produced by Myanmar Geo-science Society, seismic vulnerability analysis was done. Socio-economic profiling and inventory of critical infrastructures of Pyay City is undertaken by surveying in the field. City level seismic risk assessment of building structures are evaluated for different earthquake scenarios for Pyay City. Using the analysis data of representative buildings and the Base maps, Seismic Risk Map is prepared. Chapter 1 of this report will be introduction parts enumerating objectives and scope of the project. Chapter 2 describes the overall framework of the methodology. Chapter 3 discusses inventory data, including demographic, building data attributes required to perform damage and loss estimation. HAZUS analysis and results are described in Chapter 4. Chapter 5 explains the discussions and recommendations of the results.

2. METHODOLOGY

The HAZUS methodology and Earthquake Model is used for loss estimation in this project. Analysis is performed with two portions: identification of element of risk and estimation of vulnerability, and assessment of seismic risk.

Firstly, element of risk are identified and vulnerability are estimated for the current condition of Pyay City. All aspects of the demographic aspects and built environment, such as locations, numbers, occupancies and square footage of the buildings are prepared in a formatted database using GIS based technologies. These inventories are collected by field surveying in the project area and are used as input data in HAZUS loss estimation. The methodology estimates the several levels of damage based on the level of inventory data availability, ground motion and ground failure of Earthquake Scenario for the analysis.

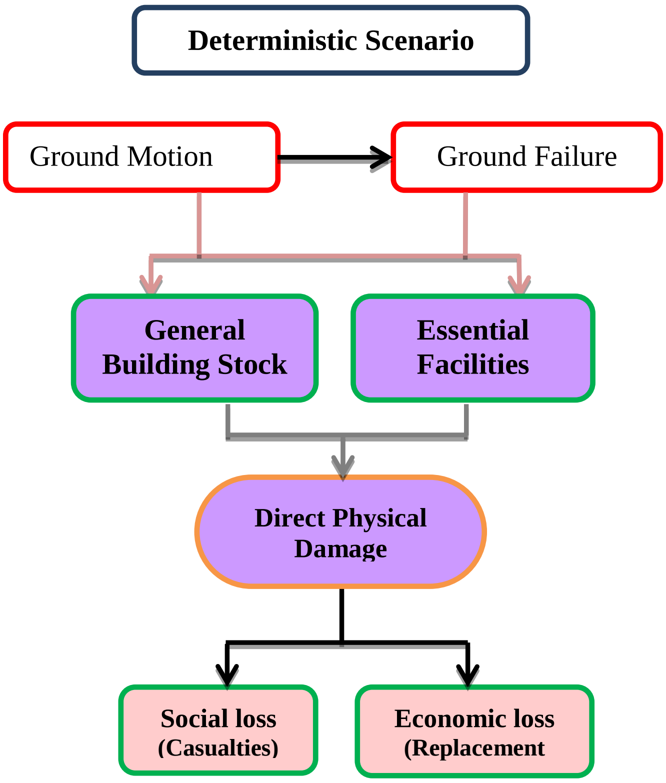

Figure (2.1) Flowchart of the Earthquake Loss Estimation Methodology adopted by HAZUS

For assessment of seismic risk, seismic ground motion demand is considered. Normally, three options are available for computations of seismic ground motion demand: (1) deterministic calculation, (2) probabilistic maps, and (3) user-supplied maps (HAZUS MH MR 5 Technical Manual). Deterministic calculation will be used by choosing maximum probable scenario earthquake magnitude and location that is relevant for Pyay City. Maximum probable scenario earthquakes are taken from past research work by Myanmar Geo-science Society. Figure (2.1) shows the contents of the HAZUS methodology used for this project.

3. GENERAL DESCRIPTION OF THE STUDY AREA AND EARTHQUAKE SCENARIO PARAMETERS

3.1 Pyay City

Pyay City is located on East Bank of the Ayerwady River and is 260 km north-west of Yangon City, the commercial city of Myanmar. Pyay City location is shown in Figure (3.1). The city is 304.41 square mile (194820 acre) wide with a population of around 113620. In Pyay City, there are total 10 wards, namely; Sin Su, Na Win, San Taw, Ywar Bal, Khit Ta Yar Myo Thit, Kyaung Gyee Oo Tan, Shwe Ku, Shwe Ta Gar, Aung San Pyi Tar Yar, and Na Wa Day Ward. Among the wards, Ywar Bal Ward has the highest population of more than 30,000, occupying one third of the total population in Pyay City Area.

Fig (3.1) Location Map of Pyay City

3.2 Building Inventory

Building inventory covers the general building stock, essential facilities and related replacement cost data. These data are correlated with direct damage data and replacement cost is concerned with economic loss. Detailed are described in the following sections.

3.2.1 General Building Stock

General building stock includes building data such as square footage by occupancy, full replacement value by occupancy, building count by occupancy, general occupancy mapping and demographic.

- ❖ **Square footage by occupancy** - This data is the estimated floor area by specific occupancy (e.g., COM1). For viewing by the user, these data are also rolled up to the general occupancies (e.g., Residential).
- ❖ **Full replacement value by occupancy** - This data provides the user with estimated replacement values by specific occupancy (e.g., RES1). For viewing by the user, these data are also rolled up to the general occupancies (e.g., Commercial).
- ❖ **Building count by occupancy** - These data provide the user with an estimated building count by specific occupancy (e.g., IND1). For viewing by the user, these data are also rolled up to the general occupancies (e.g., Government).
- ❖ **General occupancy mapping** - These data provide a general mapping for the GBS inventory data from the specific occupancy to general building type (e.g., Timber).
- ❖ **Demographic** - This table provides housing and population statistics for the study region.

Inventory data of structural occupancies are considered for residential, commercial, industrial, agricultural, religious, government, and educational buildings, is prepared as per HAZUS requirement. Estimated building count data by occupancy class for each ward is directly collected from the field visiting the ward level officer through General Administration Department. Structural occupancies are considered for 5 structural types (W1, RM, URM, C3, and MH). Structural type definitions used for this analysis are mentioned in Table (3.1). See the distribution of structural Types in Pyay City in Table (3.2) below.

Table (3.1) Definitions of Structural Type

W1(Timber)	Wood, Light Frame (<5,000 sq.ft)
RM (Brick Nogging)	Unreinforced Masonry Bearing Walls with Wood Diaphragms
URM (Brick Masonry)	Unreinforced Masonry Bearing Walls
C3 (Reinforced Concrete)	Concrete Frame with Unreinforced Masonry Infill Walls
MH (Mixed-use)	Other type of Building or Mixed use Buildings

Table (3.2) Distribution of Structural Types in Pyay City

Ward Name	Timber	Brick Masonry	Brick Nogging	Reinforced Concrete	Mixed- use	Total
Sin Su	185	170	862	297	79	1593
Na Win	434	378	2023	695	174	3704
San Taw	217	184	1007	347	89	1844
Ywar Bal	636	619	3104	1079	196	5634
Khit Yayar Myo Thit	325	278	1540	554	125	2822
Kyaung Gyi Oo Tan	99	89	468	177	39	872
Shwe Ku	57	50	264	105	22	498
Shwe Ta Gar	213	202	992	342	87	1836
Aung San Pyi Tharyar	222	189	1048	365	93	1917
Nawaday	88	87	443	180	36	834

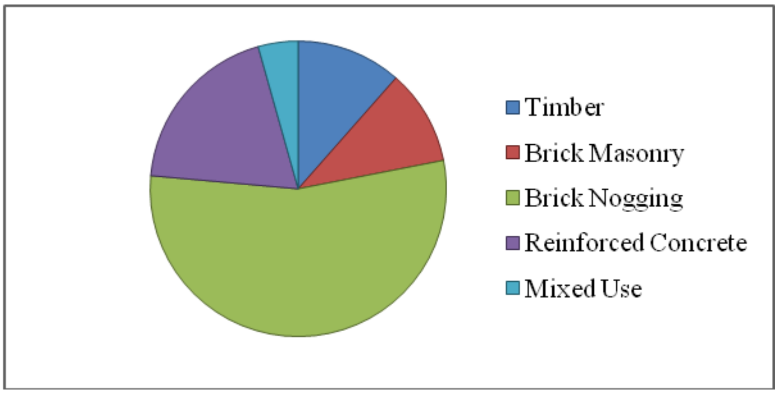

Figure (3.2) Number of Buildings in term of Structural Type

The inventory information required for the analysis to estimate the probability of damage to occupancy classes is the relationship between the specific occupancy class and the model building type. The occupancy mapping is created from the statistical distribution of on-street survey data.

In Pyay City, brick nogging building type (Unreinforced Masonry Bearing Walls with Wood Diaphragms) is the most commonly built type in Pyay City (Figure 3.2). Numbers of buildings in detailed occupancy classes are shown in Table (3.3).

Table (3.3) Distribution of Occupancy Types in Pyay City

Ward Name	Residential	Commercial	Medical	Religious	Industrial	Government	Education
Sin Su	1506	24	0	46	0	17	0
Na Win	3487	127	10	41	2	10	27
San Taw	1757	61	8	8	0	4	6
Ywar Bal	4027	1253	10	265	63	14	2
Khit Yayar Myo Thit	2454	327	2	21	0	16	2
Kyaung Gyi Oo Tan	761	89	3	2	0	12	5
Shwe Ku	396	85	5	2	0	7	3
Shwe Ta Gar	1704	51	10	64	0	5	2
Aung San Pyi Tharyar	1810	68	8	12	2	4	13
Nawaday	661	112	1	41	15	1	3

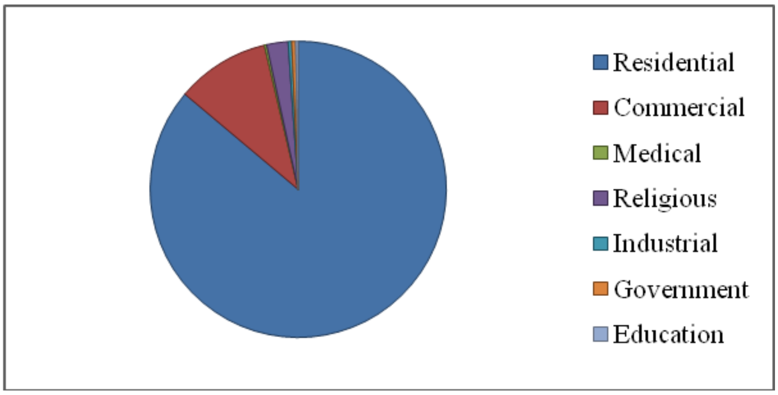

Figure (3.3) Number of Buildings in term of Occupancy Type

There are around 113,620 populations in Pyay City. Among the wards, Ywar Bal Ward has the highest number of population (approximately 30,000), more than one third of total population in Pyay City, and Nawaday Ward has the least population (more than 3,000). Damage during disaster tends to be more severe in areas of high population densities. When we say with population density, Khit Ta Yar Myo Thit, the industrial zone area, has the highest population density. Refer to Figure A-1 and Figure A-2 for population and population density.

Moreover, population data is collected grouping into two categories; age over 18 and under 18. As per survey data enumerated in Figure A-3 and Figure A-4, it can be seen that Shwe Da Gar and San Taw have the largest number of population aged over 18. Khit Ta Yar Myo Thit, which is the industrial zone, has the lowest number of population aged over 18 and highest number of population under 18.

Population data are also expressed with Female to Male Ratio. This information is important as female are normally weak in disaster response, and the more the female to male ratio, the more probability that area can result in higher damage. As can be seen from Figure A-5, Na Win, Kyaung Kyi Oo Tan, and Shwe Ku Wards have the largest female to male ratio in compared to other. Nawaday Ward has the least female to male ratio. It can be noted that female to male ratio is larger than one for all wards, meaning there are more female in Pyay.

Household and building count data plays an important role in calculating risk assessment. The number of households in Na Win and Ywar Bal are the largest number whereas Shwe Ku ward has smallest number of households (Figure A-6). The building count data is directly collected from each ward by field survey. Na Win and Ywar Bal has the highest number of building count in Pyay (Figure A-7). As can be seen from Figure A-8, Khit Ta Yar Myo Thit Ward has the highest building density in Pyay City, while Shwe Ku Ward has the lowest number of building count and building density.

3.2.2 Essential Facilities

Essentials facilities include infrastructures like school, hospital, fire station, police station, street, main road, and railway. These data are shown in Figure A-9 with respected location. There are 8 nos. of hospitals in Pyay City, 7 are private and the rest one is government hospitals. There are 31 schools and 2 universities; Pyay University and Computer University Pyay. There are total 3 nos. of police stations and 1 fire station.

3.2.3 Replacement Cost

The economic loss estimated for the earthquake is expressed by millions of dollars which includes building and lifeline related losses based on the region's available inventory. It is collected based on data from City Development Organization in Pyay City calculating with the current cost of construction materials and labor cost.

3.3 Earthquake Scenario Parameters

Deterministic calculation is used in this research for determining earthquake scenario parameters. For deterministic calculation of ground shaking, a scenario earthquake magnitude and location are required to specify. For Earthquake scenario for Pyay City, seismic hazard assessment report from Myanmar Geo-science Society is referred and these parameters are used in risk assessment. Pyay Thrust, shown in figure (3.4), is used in estimating maximum probable earthquake scenario.

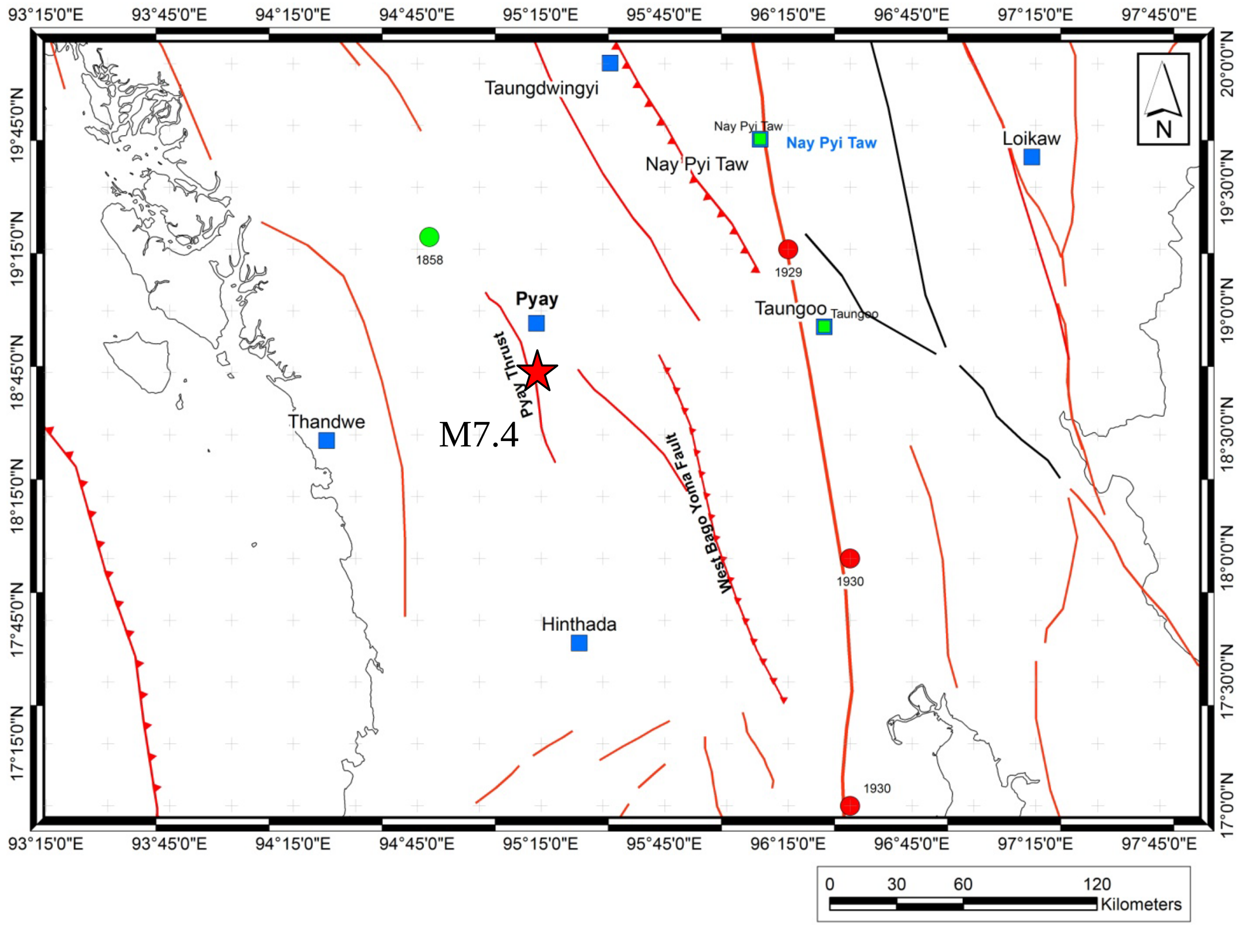

Figure (3.4) Active Fault around Pyay City (Source; MGS)

Maximum probable earthquake for Pyay city is estimated near Padaung Segment of Pyay Thrust. Detailed information for scenario earthquake is shown in Table (3.9). In this analysis, Attenuation equation we used is Boore.Joyner and Fumal(1997). This equation was confirmed by Department of Meteorology and Hydrology (Nay Pyi Daw) that based on geological condition of Myanmar.

Table (3.9) Maximum Probable Earthquake Scenario (Pyay Thrust)

Scenario Name	Pyay Earthquake (Pyay Thrust on Padaung Segment)
Type of Earthquake	Arbitrary
Longitude of Epicenter	-116.68
Latitude of Epicenter	34.72
Earthquake Magnitude	7.4
Depth (km)	10.00
Rupture Length (km)	84.33
Rupture Orientation (degree)	170.00
Attenuation Function	Boore. Joyner and Fumal (1997)

4. HAZUS ANALYSIS AND RESULTS

4.1 Direct Earthquake Damage

Damage states are defined separately for structural and nonstructural systems of a building. Damage is described by one of four discrete damage states: slight, moderate, extensive, and complete. All Damage States descriptions for different type of structural types are as shown in Appendix Table B-1 with detailed explanations. Direct earthquake damage deals with buildings and facilities; the general building stock, essential facilities, and high potential loss facilities.

4.1.1 Total Building Damage

The building damage maps shown in Appendix B1~B8 are the results of maximum probable earthquake scenario in term of building damage with respect to building types and damaged state. In Pyay Thrust scenario earthquake, HAZUS estimates that about 20,899 buildings will be at least moderately damaged. This is over 97.00 % of the total number of buildings in the region. There are an estimated 16,938 buildings that will be damaged beyond repair. Table (4.1) below summarizes the expected damage by general occupancy for the buildings in the region. Table (4.2) below summarizes the expected damage by general building type.

Table (4.1) Expected Building Damage by Occupancy

Occupancy	Total Number of Building	No Damage	Slight Damage	Moderate Damage	Extensive Damage	Complete Damage
Agriculture	2	0	0	0	0	2
Commercial	2,254	12	47	138	199	1,858
Education	63	0	0	1	3	59
Government	39	0	0	1	2	36
Industrial	82	1	4	10	10	57
Other Residential	1,667	9	35	103	151	1,369
Religious	501	0	1	9	29	462
Single Family	16,897	100	406	1,154	1,628	13,609

Table (4.2) Expected Building Damage by Building Type (All Design Levels)

Building Type	Total Number of Building	No Damage	Slight Damage	Moderate Damage	Extensive Damage	Complete Damage
Timber	2,464	114	447	981	628	294
Reinforced Concrete	4,137	1	3	37	53	4,043

Brick Nogging	11,745	5	37	338	1,126	10,239
Brick Masonry	2,238	1	5	43	153	2,036
Mixed Use	922	0	2	18	63	839

4.1.2 Total Essential Facilities Damage

Essential facilities that provide services to public and should be functional after an earthquake are also included in risk assessment. On the day of the earthquake, it is estimated that 100% of essential facilities are available for use by patients already in the hospitals and those injured by the earthquake.

4.2 Induced Earthquake Damage – Debris Generation

HAZUS estimated that the amount of debris generated by earthquake in two categories; (1) brick/ timber, and (2) reinforced concrete/ steel. It is distinguished based on their different of material handling equipment required to handle the debris. According to analysis result, it is estimated that a total of 3.36 million tons of debris will be generated at the time of the scenario earthquake. Of the total amount, brick/ timber comprises 35 % of the total, with the remainder being reinforced concrete/ steel. If the debris tonnage is converted to an estimated number of truckloads, it will require 134,400 truckloads (@25 tons/ truck) to remove the debris generated by the earthquake.

4.3 Casualties

HAZUS estimates that the number of people that will be injured and killed by the earthquake. The casualties are broken down into four (4) severity levels that describe the extent if the injuries. The levels are described as follows;

Severity Level (1) *Injuries will require medical attention but hospitalization is not needed.*

Severity Level (2) *Injuries will require hospitalization but are not considered life-threatening.*

Severity Level (3) *Injuries will require hospitalization and can become life threatening if not promptly treated.*

Severity Level (4) *Victims are killed by the earthquake.*

The casualty estimates are provided foe three (3) times of day; 2:00 AM, 2:00 PM and 5:00 PM. These times represents the periods of the day that different sectors of the community are at their peak occupancy loads. The 2:00 AM estimate considers that the residential occupancy load is maximum; the 2:00 PM estimate considers that the educational, commercial and industrial sector loads are maximum and 5:00 PM represents peak commute time.

Table (4.3) Summary of the Casualty Estimates for Scenario Earthquake

Time	Level 1	Level 2	Level 3	Level 4
2:00 AM	6,837	2,376	425	841
2:00 PM	6,983	2,457	455	883
5:00 PM	4,686	1,643	303	588

4.4 Building Related Economic Loss

Building related economic loss is expressed in two categories: (1) direct building losses, and (2) business interruption losses. The direct building losses are the estimated costs to repair or replace the damage caused to the building and its contents. The business interruption losses are the losses associated with inability to operate a business because of the damage sustained during the earthquake. Business interruption losses also include the temporary living expenses for those people displaced from their homes because of the earthquake.

The total building-related losses were 1,718.36 (millions of dollars); 52 % of the estimated losses were related to the business interruption of the region. By far, the largest loss was sustained by the residential occupancies which made up over 68 % of the total loss. Table (4.4) below provides a summary of the losses associated with the building damage.

Table (4.4) Building Related Economic Loss Earthquake (x 10^3 Millions of Kyats)

Category	Area	Single Family	Other Residential	Commercial	Industrial	Others	Total
Income Losses	Wage	0.00	4.95	80.02	0.44	13.23	98.64
	Capital-Related	0.00	2.13	70.12	0.27	3.79	76.31
	Rental	110.89	42.95	44.19	0.27	6.45	2 04.75
	Relocation	360.93	35.96	63.49	1.08	56.40	517.86
	Subtotal	471.82	86.00	257.81	2.06	79.87	897.55
Capital Stock Losses	Structural	116.27	7.82	30.22	0.77	5.51	160.60
	Non-Structural	356.42	41.75	74.10	3.49	24.92	500.68
	Content	81.11	8.67	37.85	2.39	12.65	142. 67
	Inventory	0.00	0.00	15.29	1.55	0.02	16.85
	Subtotal	553.80	58.24	157.47	8.19	43.10	820.81
Total		1,025.62	144.24	415.28	10.25	122.97	1,718.36

5. DISCUSSIONS AND RECOMMENDATIONS

Seismic Risk Assessment is very useful risk reduction measure. Government officials, local stake holders and communities can use the risk map for disaster prevention and preparedness in Pyay City. Priorities for urban planning, land-use planning, and building regulations can be decided by the use of Risk Maps. Urban Planners can use the maps to prepare an improvement plan for existing urban structures such as reinforcement (retrofitting) of vulnerable buildings and infrastructure, securing of open spaces and emergency roads. The building damage distribution maps highlight the areas of vulnerable building stock. And it offers a window of opportunity to reduce the vulnerability of the people by implementing specific risk reduction measures such as retrofitting of buildings and have effective response plan to deal with.

Moreover, prevention measures for essential facilities such as for life saving, fire fighting and transportation can be decided. The results are also useful to communities. Understanding the vulnerability of the area where they live, to understand how to behave in case of an earthquake, and participating in preparing plans for disaster prevention are the progress for the communities.

It should be noted that HAZUS tool gives the exact number of casualties (death and injury) during scenario earthquakes which highlight how many people will require medical attention. The entire process of carrying out casualty simulation is to reach an understanding of how many people will require medical attention. It also gives better insights into the requirements of emergency services for response planning and the hospital authorities for developing hospital contingency plan. The collapse or heavy damage of buildings is considered as the main cause of death and injury during an earthquake. HAZUS casualty estimation does not take into account of casualty (Death and Injury) from non-structural hazards.

Road and street damages are not considered in calculating damages stages due to limited time of the project.

APPENDIX

Appendix A – Thematic Maps of Pyay City

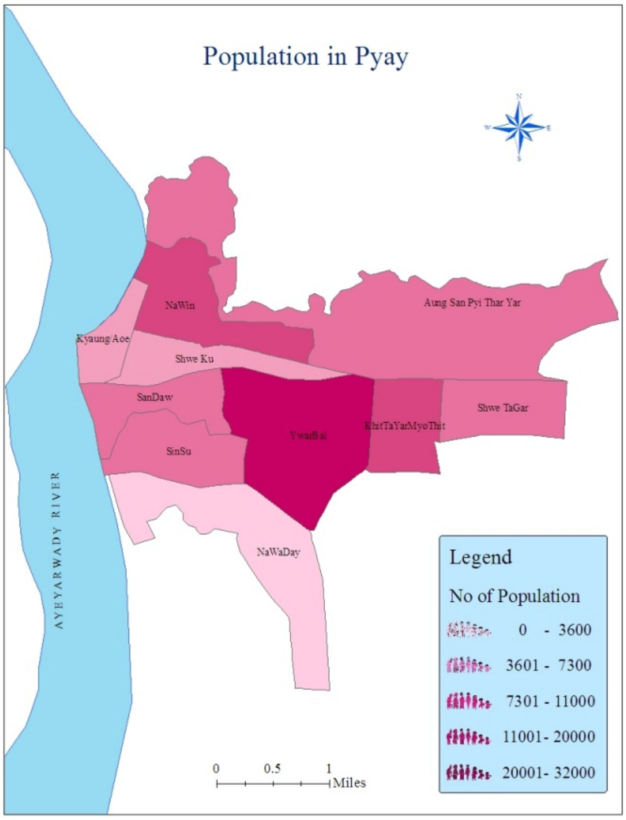

Figure A-1 Population in Pyay

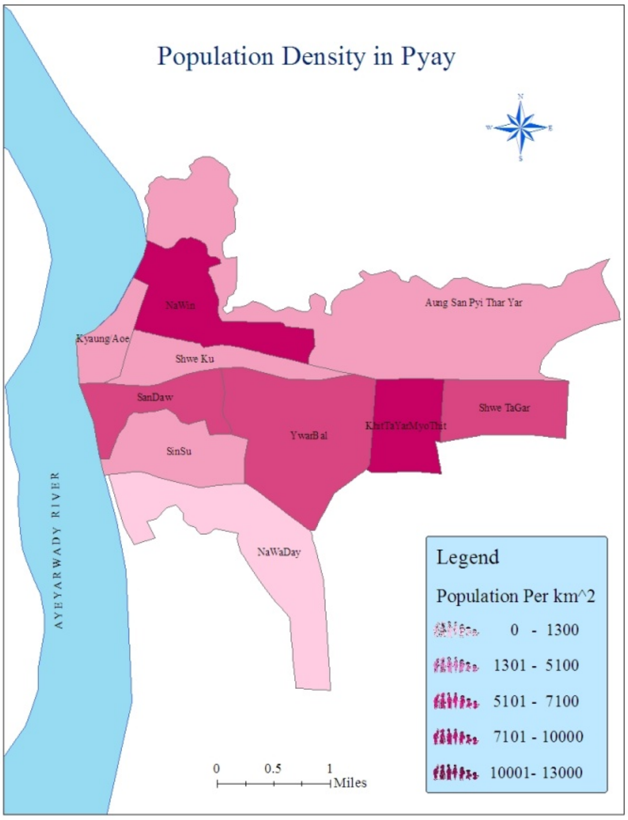

Figure A-2 Population Density in Pyay

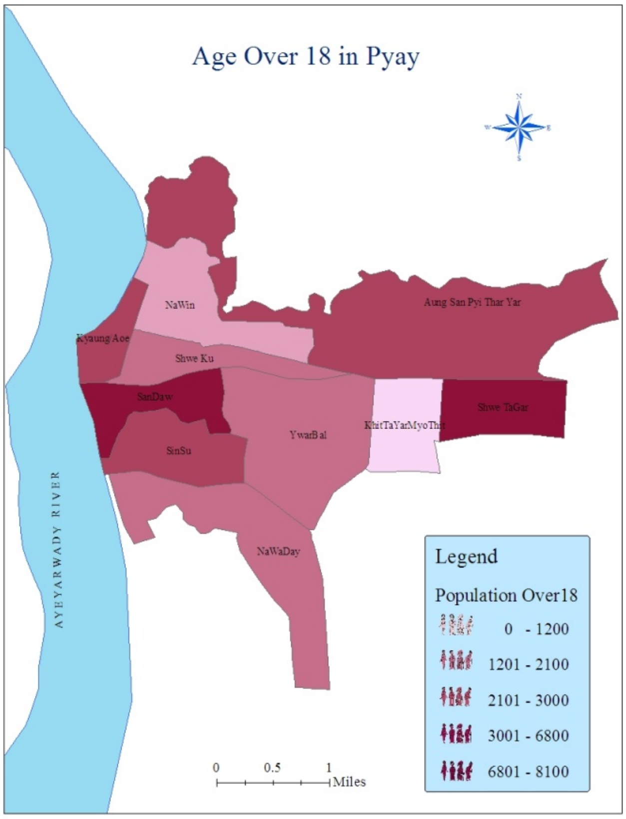

Figure A-3 Age Over 18 in Pyay

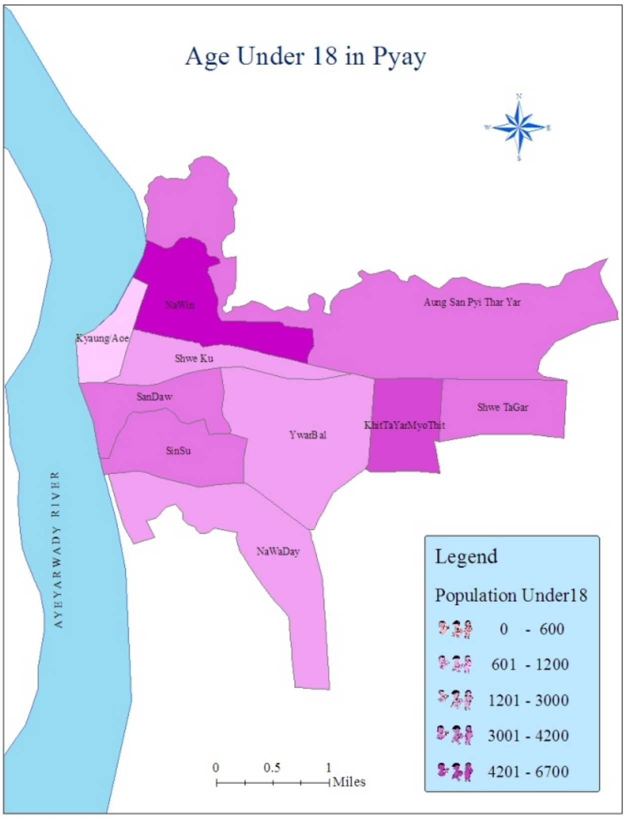

Figure A-4 Age Under 18 in Pyay

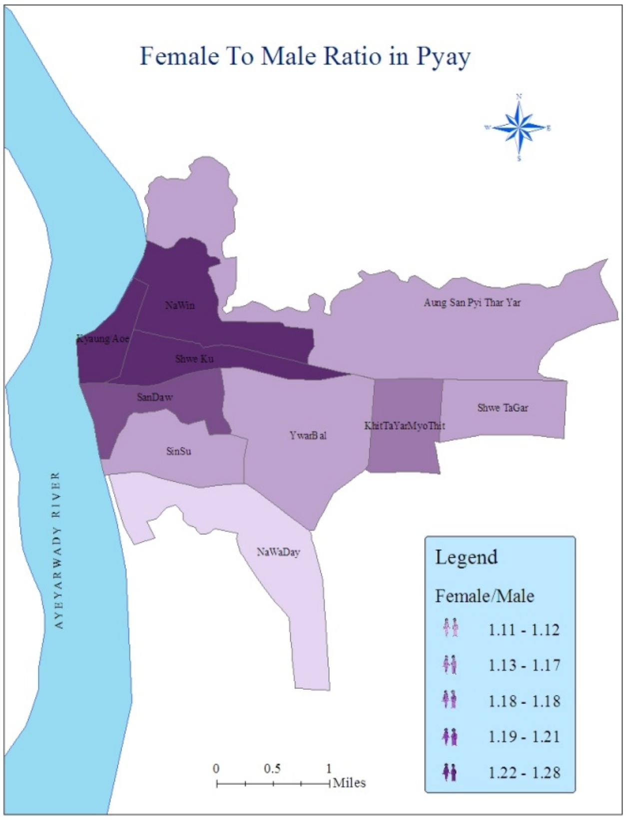

Figure A-5 Female to Male Ration in Pyay

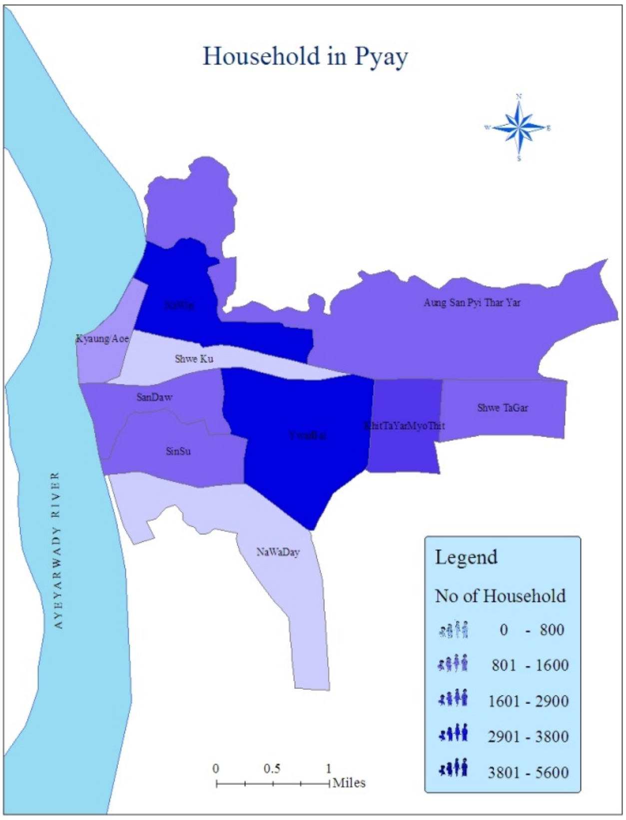

Figure A-6 Number of Households in Pyay

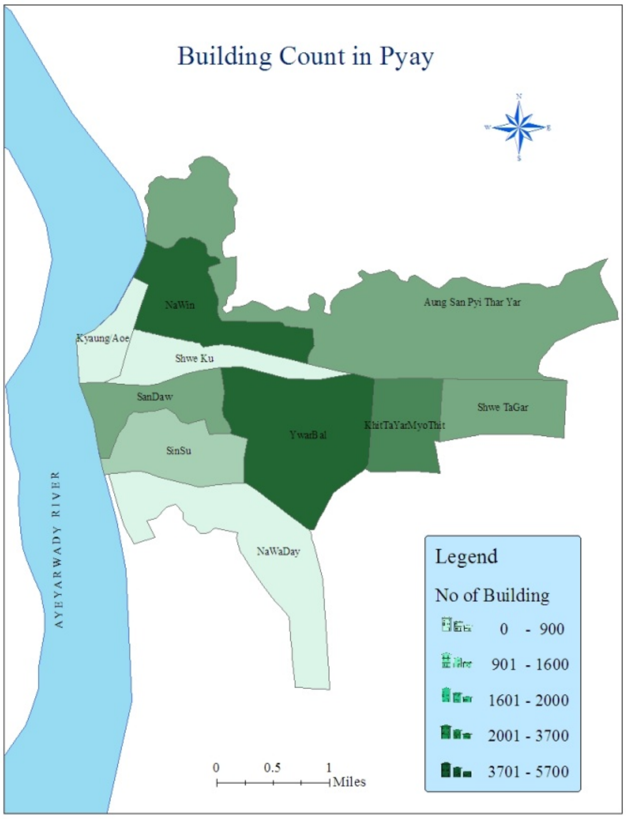

Figure A-7 Building Count in Pyay

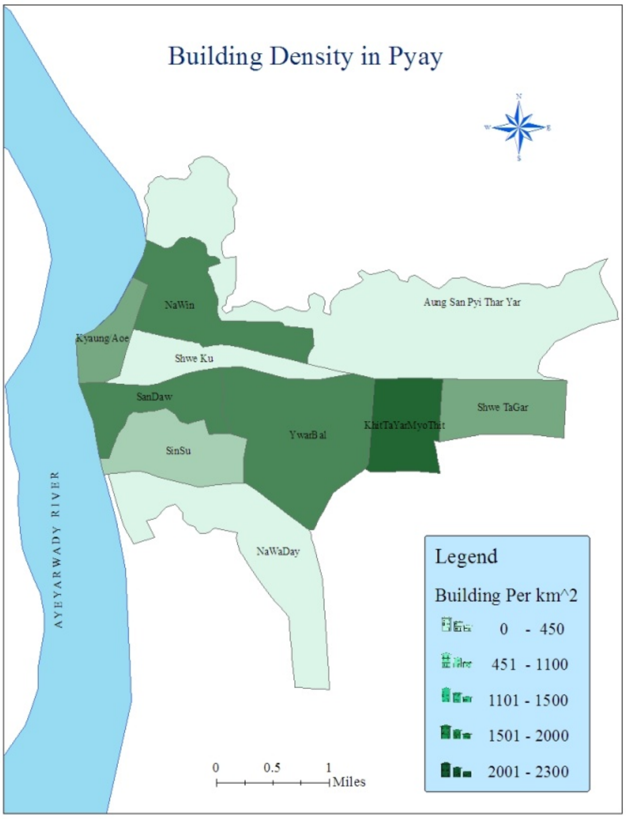

Figure A-8 Building Density in Pyay

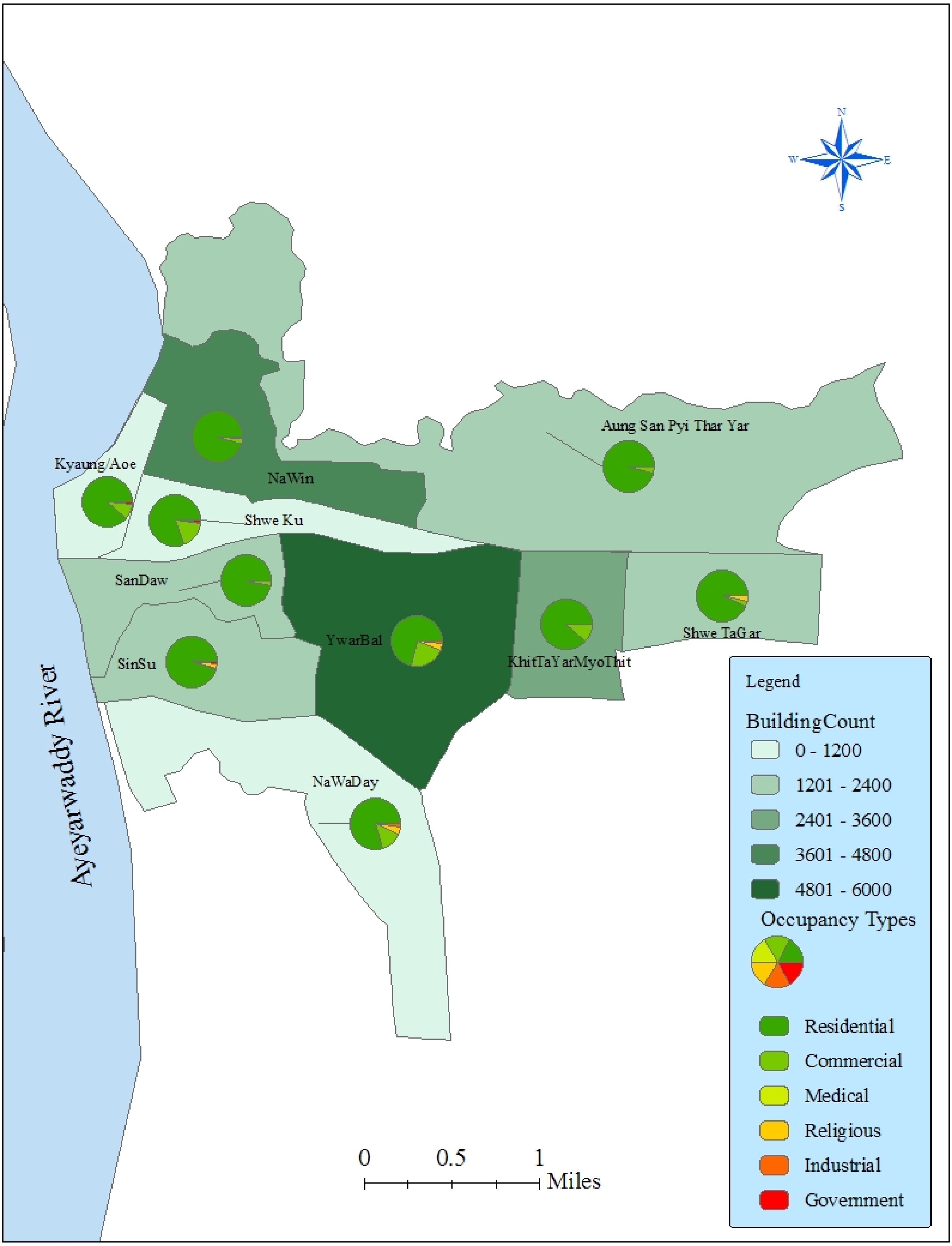

Figure A-9 Distribution of Building in Occupancy Types of Pyay City

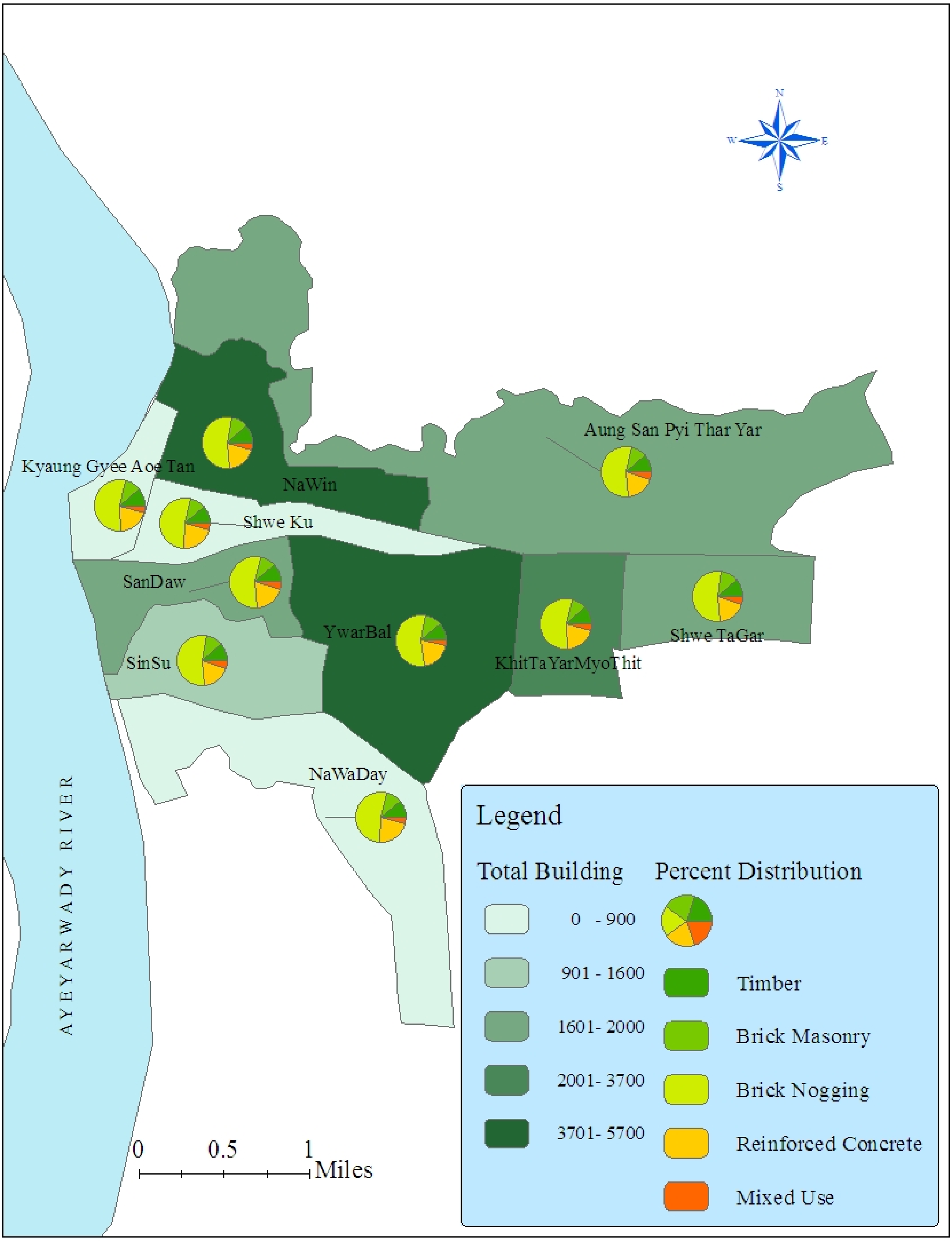

Figure A-10 Distribution of Building in Structural Types of Pyay City

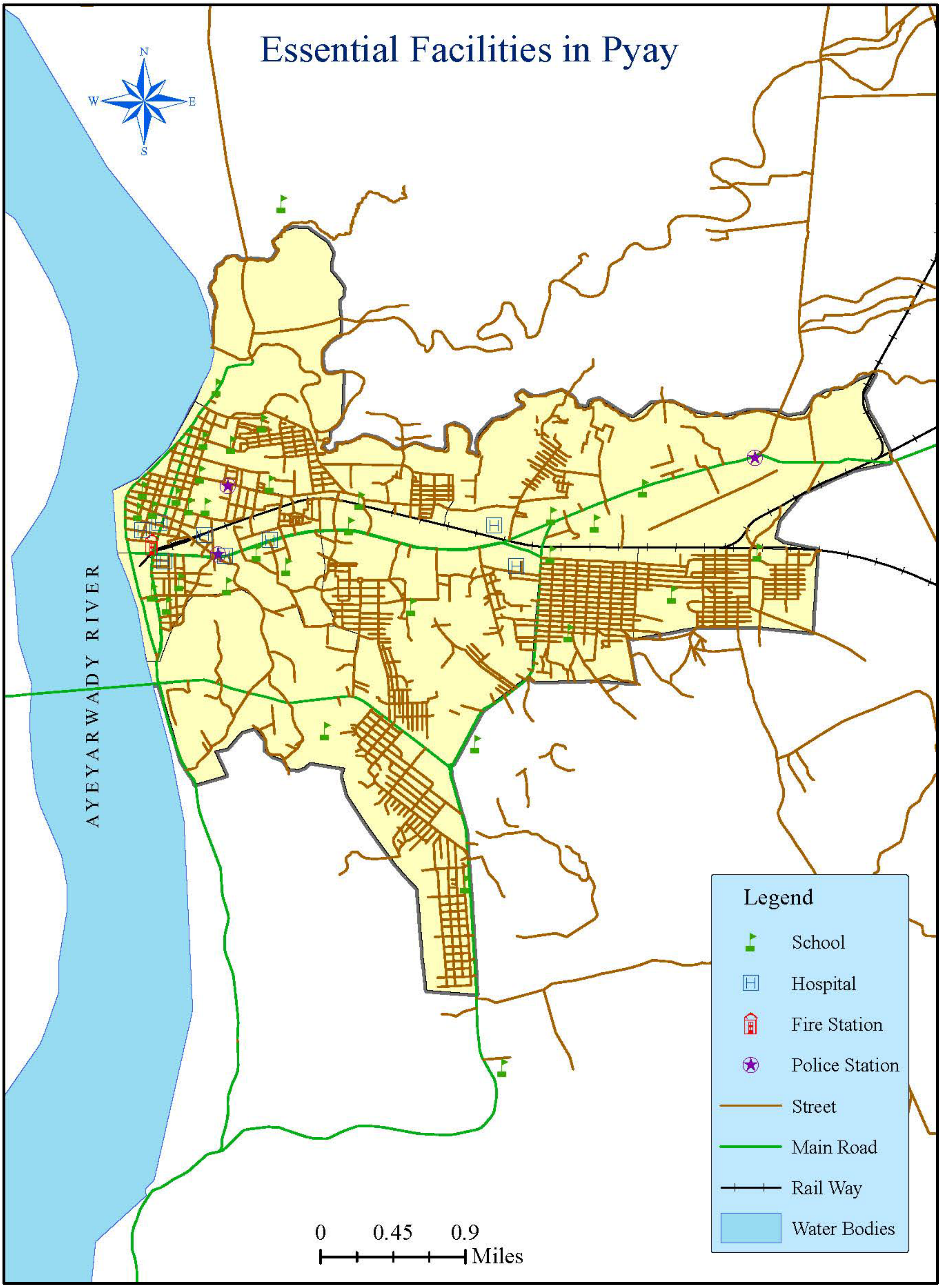

Figure A-11 Essential Facilities in Pyay City

APPENDIX

Appendix B – Damage Stage of Pyay City by Scenario Earthquake

Table B-1 Damage State Definitions (Adopted from HAZUS MH MR Technical Manual)

Damage State	Timber (W1)	Brick Nogging (RM)	Reinforced Concrete (C3)	Brick Masonry (URM)	Mixed-use (MH)
Slight	Small timber-board cracks at corners of door and window openings and wall-ceiling intersections	Diagonal hairline cracks on masonry wall surfaces; larger cracks around door and window openings in walls with large proportion of openings; minor separation of walls from the floor and roof diaphragms	Diagonal (sometimes horizontal) hairline cracks on most infill walls; cracks at frame-infill interfaces.	Diagonal, stair-step hairline cracks on masonry wall surfaces; larger cracks around door and window openings in walls with large proportion of openings; movements of lintels; cracks at the base of parapets.	Small timber-board cracks at corners of door and window openings and wall-ceiling intersections. Diagonal hairline cracks on masonry wall surfaces; larger cracks around door and window openings in walls with large proportion of openings; minor separation of walls from the floor and roof diaphragms.
Moderate	Large timber-board cracks at corners of door and window openings.	Most wall surfaces exhibit diagonal cracks; some of the shear walls have exceeded their yield capacities indicated by larger diagonal cracks. Some walls may have visibly pulled away from the roof.	Most infill wall surfaces exhibit larger diagonal or horizontal cracks; some walls exhibit crushing of brick around beam-column connections. Diagonal shear cracks may be observed in concrete beams or columns.	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. 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.	Large timber-board cracks at corners of door and window openings. Most wall surfaces exhibit diagonal cracks.
Extensive	Large cracks at plywood joints; splitting of wood sill plates and/or slippage of structure over foundations; small foundations cracks.	In buildings with relatively large area of wall openings most walls have exceeded their ultimate capacities indicated by large, through-the-wall diagonal cracks and visibly buckled wall. The wood diaphragms may exhibit cracking and	Most infill walls exhibit large cracks; some bricks may dislodge and fall; some infill walls may bulge out-of-plane; few walls may fall partially or fully; few concrete columns or beams may fail in shear resulting	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.	Large cracks at plywood joints; splitting of wood sill plates and/or slippage of structure over foundations; small foundations cracks. The wood diaphragms may exhibit cracking and separation along wood joints. Partial collapse of the roof may result from failure of the wall-to-diaphragm anchorages or

		separation along wood joints. Partial collapse of the roof may result from failure of the wall-to-diaphragm anchorages or the connections of beams to walls.	in partial collapse. Structure may exhibit permanent lateral deformation.		the connections of beams to walls.
Complete	Structure may have large permanent lateral displacement, may collapse, or be in imminent danger of collapse due to the failure of the lateral load resisting system; some structures may slip and fall off the foundations; large foundation cracks. Approximately 3% of the total area of W1 buildings with complete damage is expected to be collapsed.	Structure has collapsed or is in imminent danger of collapse due to failure of the wall anchorages or due to failure of the wall panels. Approximately 13% (low-rise) or 10% (mid-rise) of the total area of RM1 buildings with complete damage is expected to be collapsed	Structure has collapsed or is in imminent danger of collapse due to a combination of total failure of the infill walls and non-ductile failure of the concrete beams and columns. Approximately 15% (low-rise), 13% (mid-rise) or 5% (high-rise) of the total area of C3 buildings with complete damage is expected to be collapsed.	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 URM buildings with complete damage is expected to be collapsed	Structure may have large permanent lateral displacement, may collapse, or be in imminent danger of collapse due to the failure of the lateral load resisting system; some structures may slip and fall off the foundations; large foundation cracks. Approximately 3% of the total area of buildings with complete damage is expected to be collapsed.

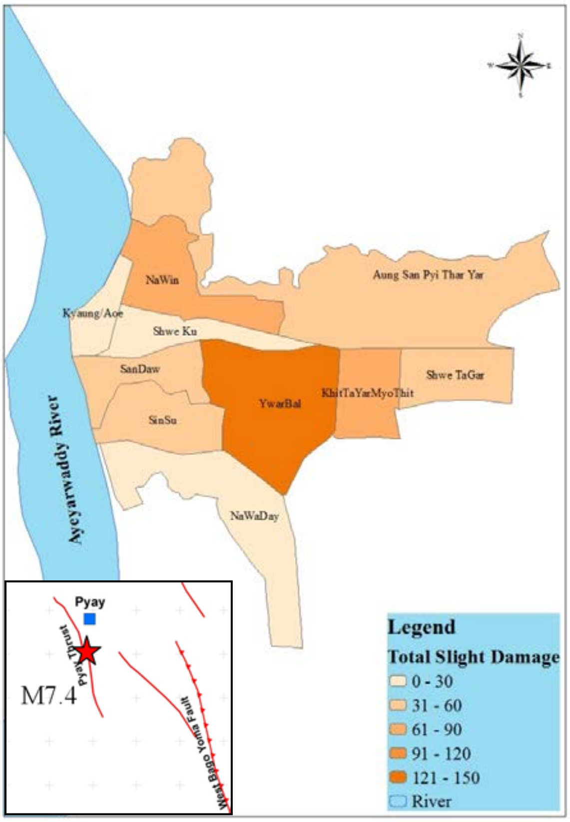

Figure B-1 Total Slight Damage Buildings in Pyay by Scenario Earthquake

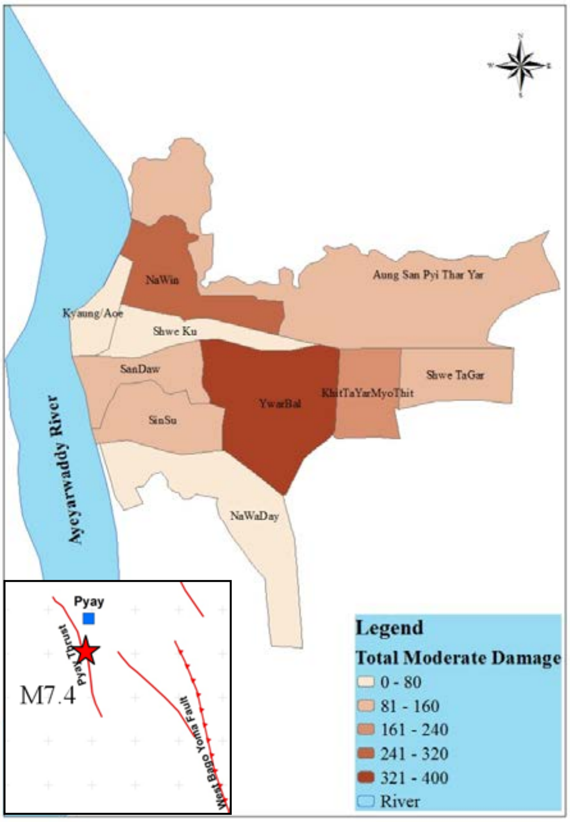

Figure B-2 Total Moderate Damage Buildings in Pyay by Scenario Earthquake

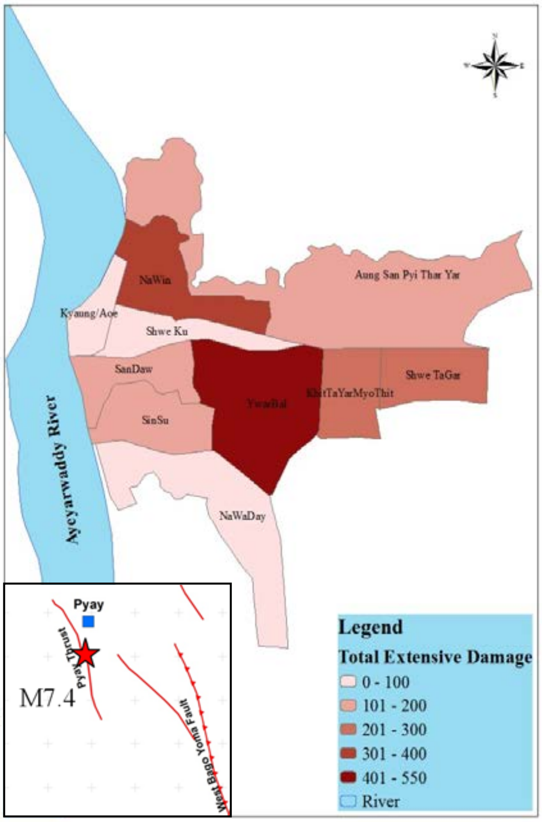

Figure B-3 Total Extensive Damage Buildings in Pyay by Scenario Earthquake

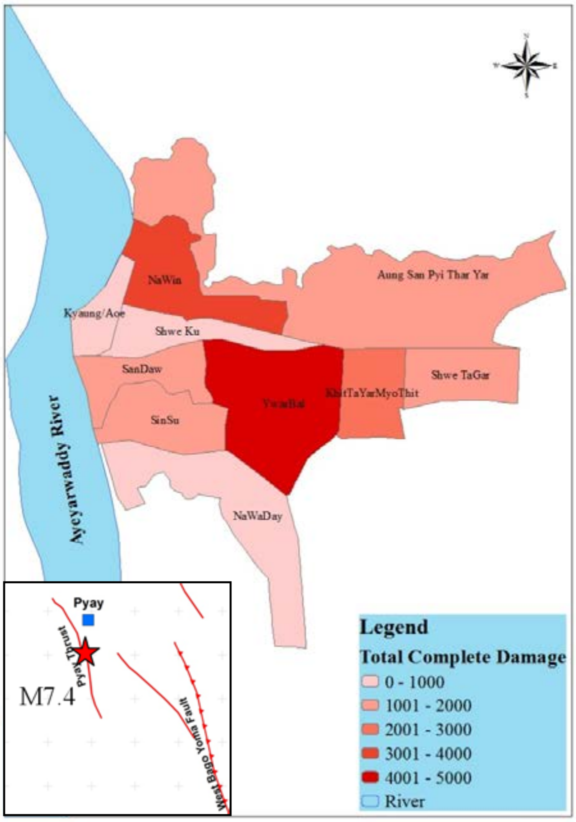

Figure B-4 Total Complete Damage Buildings in Pyay by Scenario Earthquake

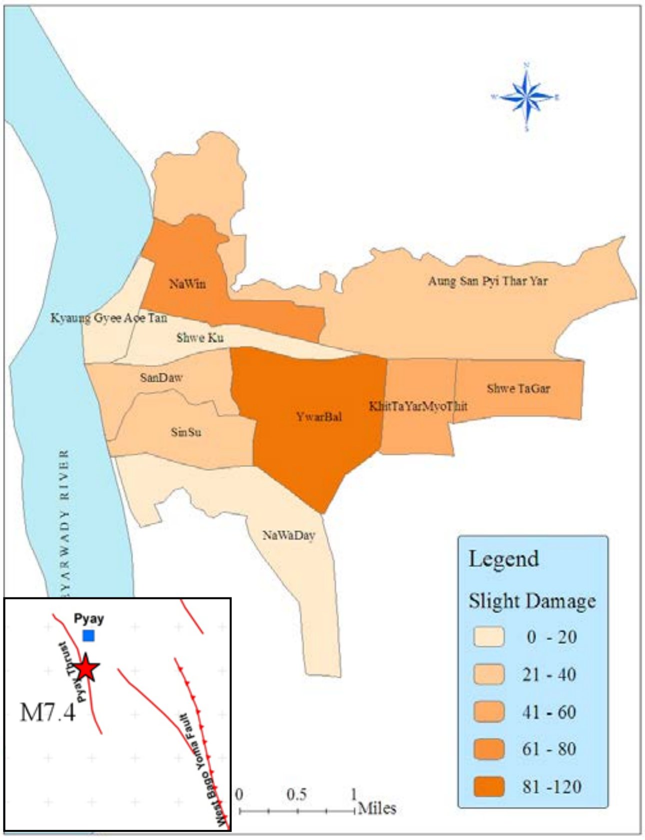

Figure B-5 Slight Damage of Timber Buildings in Pyay by Scenario Earthquake

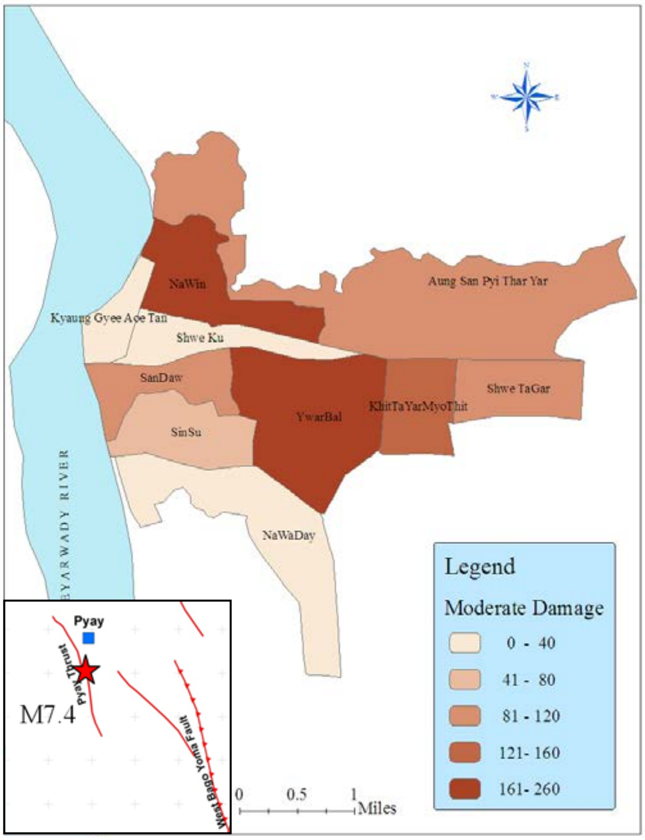

Figure B-6 Moderate Damage of Timber Buildings in Pyay by Scenario Earthquake

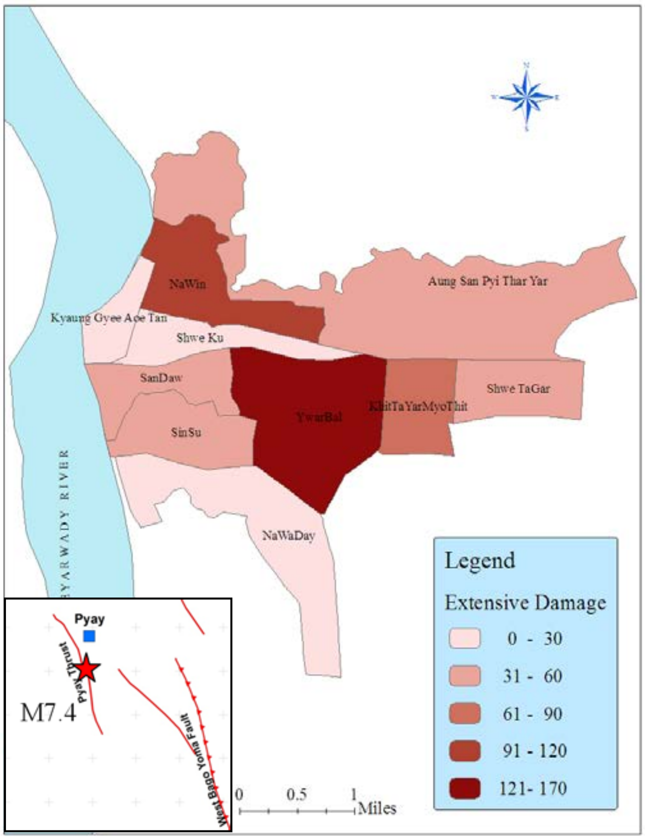

Figure B-7 Extensive Damage of Timber Buildings in Pyay by Scenario Earthquake

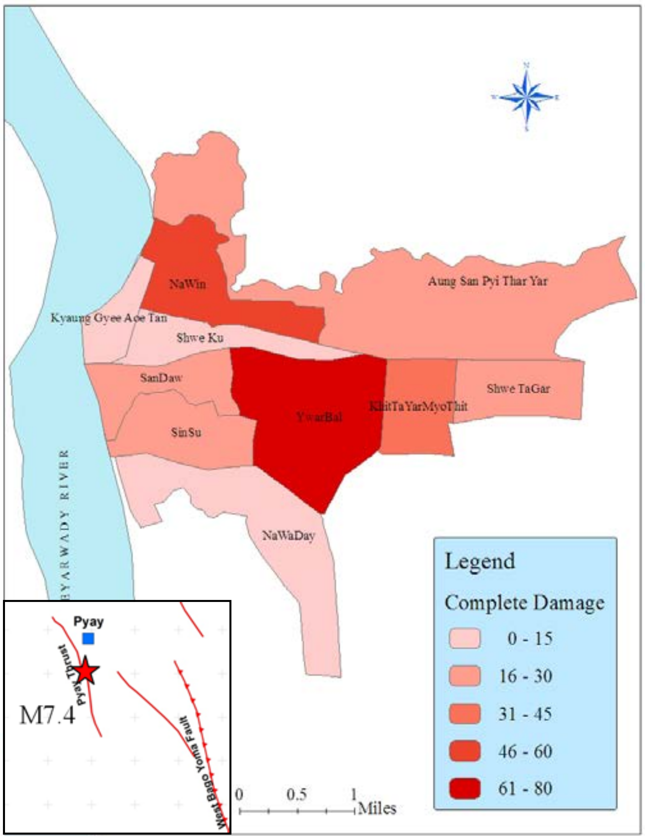

Figure B-8 Complete Damage of Timber Buildings in Pyay by Scenario Earthquake

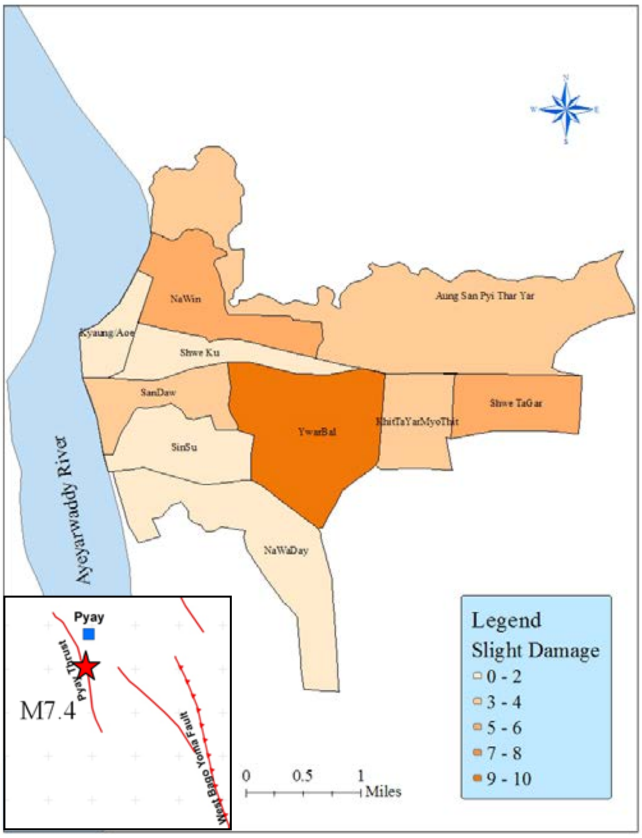

Figure B-9 Slight Damage of Brick Nogging Buildings in Pyay by Scenario Earthquake

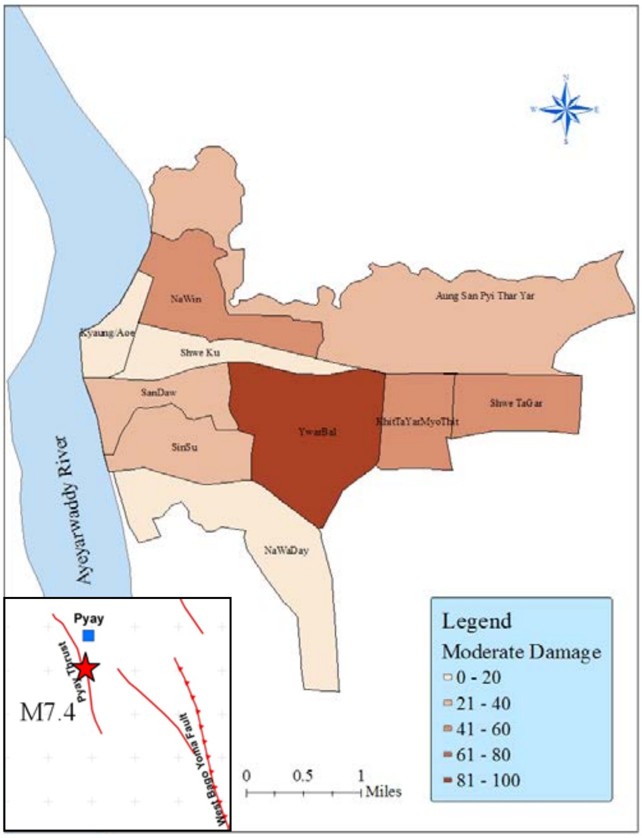

Figure B-10 Moderate Damage of Brick Nogging Buildings in Pyay by Scenario Earthquake

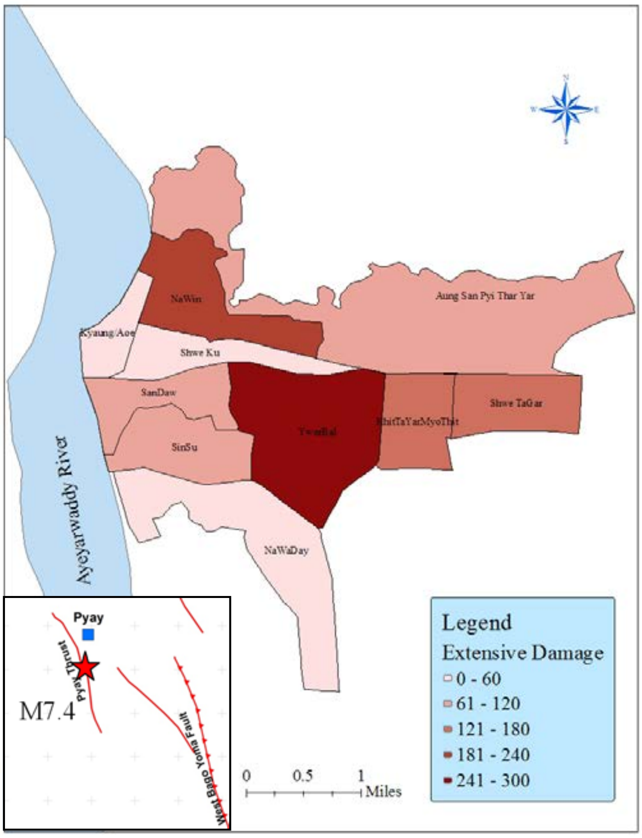

Figure B-11 Extensive Damage of Brick Nogging Buildings in Pyay by Scenario Earthquake

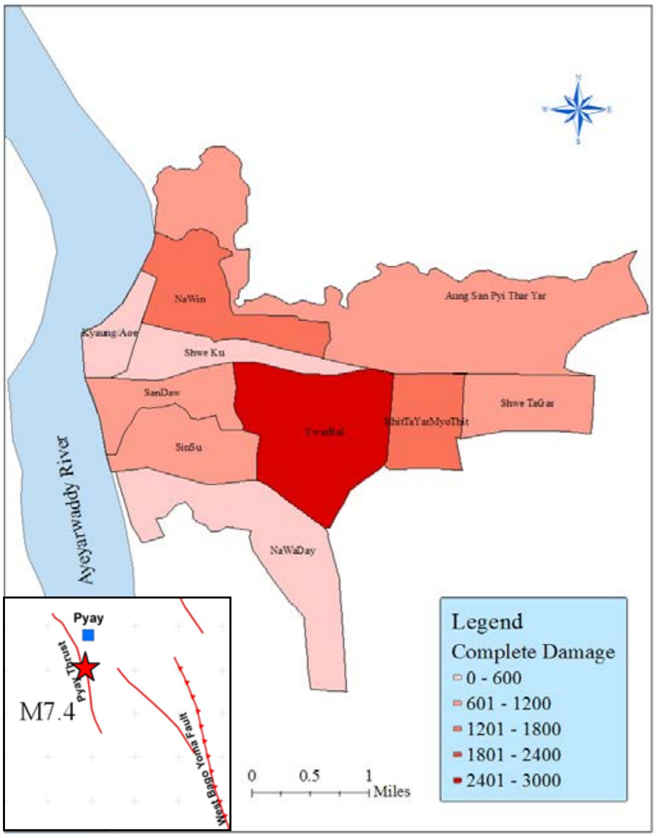

Figure B-12 Complete Damage of Brick Nogging Buildings in Pyay by Scenario Earthquake

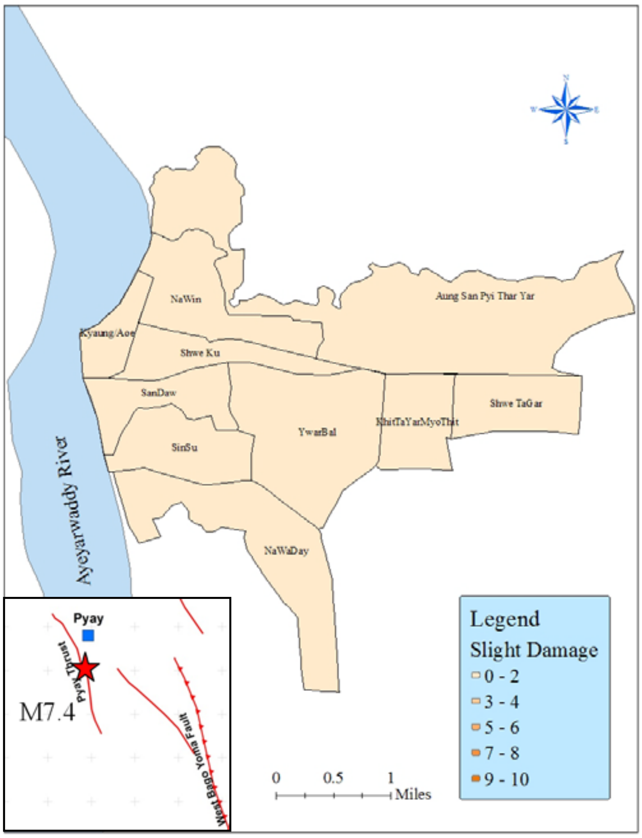

Figure B-13 Slight Damage of Reinforced Concrete Buildings in Pyay by Scenario Earthquake

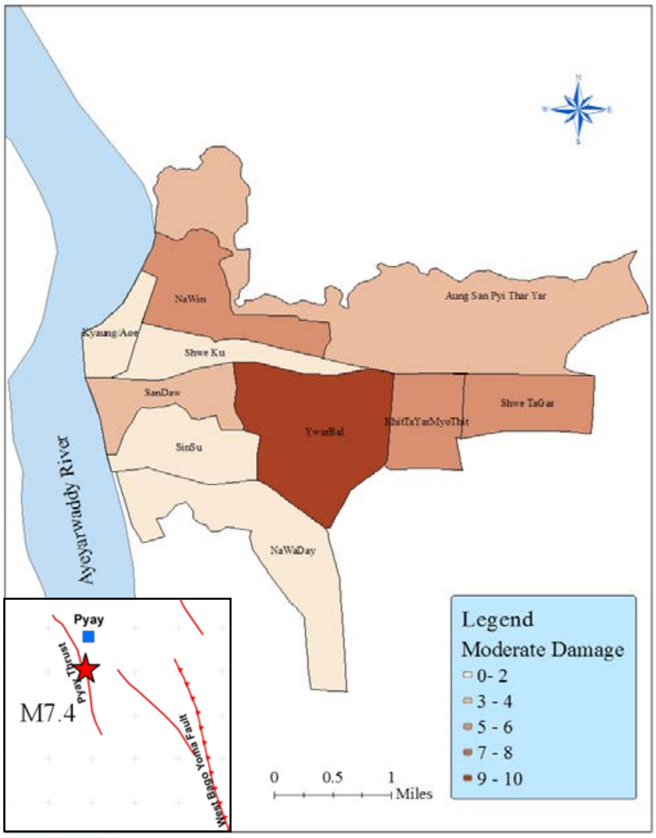

Figure B-14 Moderate Damage of Reinforced Concrete Buildings in Pyay by Scenario Earthquake

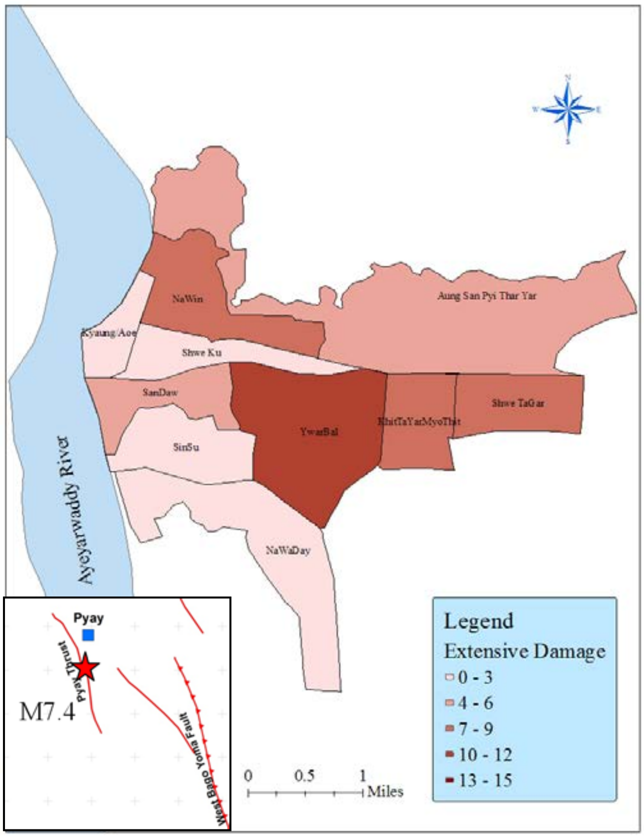

Figure B-15 Extensive Damage of Reinforced Concrete Buildings in Pyay by Scenario Earthquake

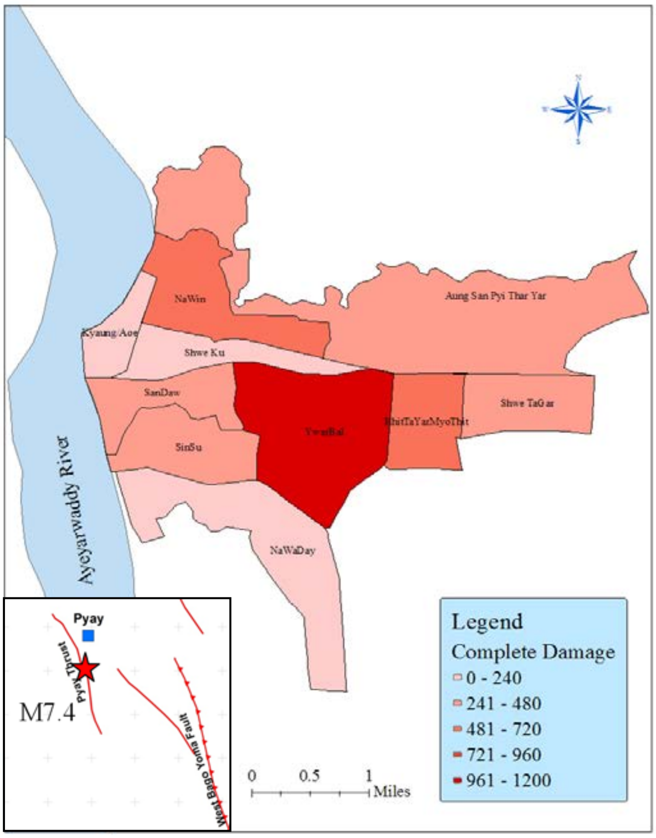

Figure B-16 Complete Damage of Reinforced Concrete Buildings in Pyay by Scenario Earthquake

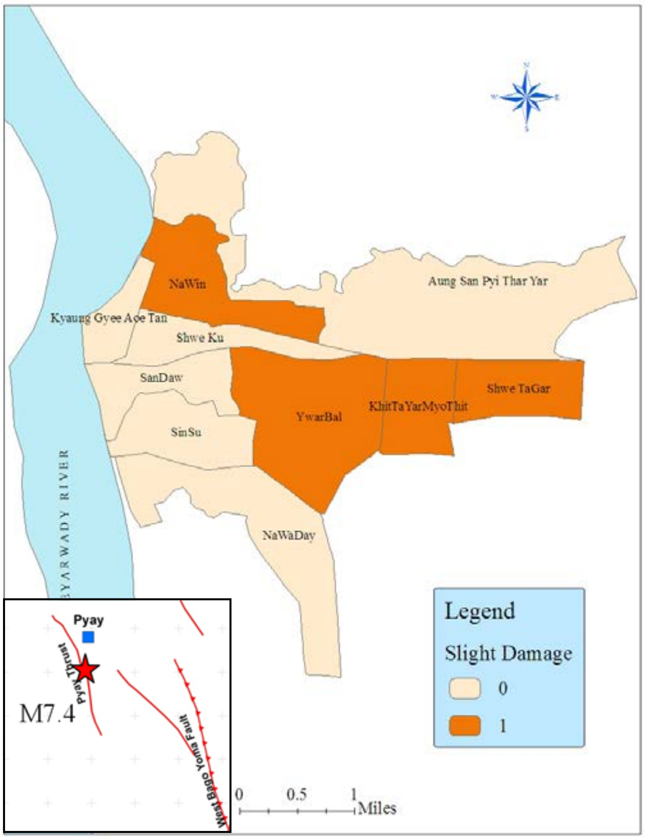

Figure B-17 Slight Damage of Brick Masonry Buildings in Pyay by Scenario Earthquake

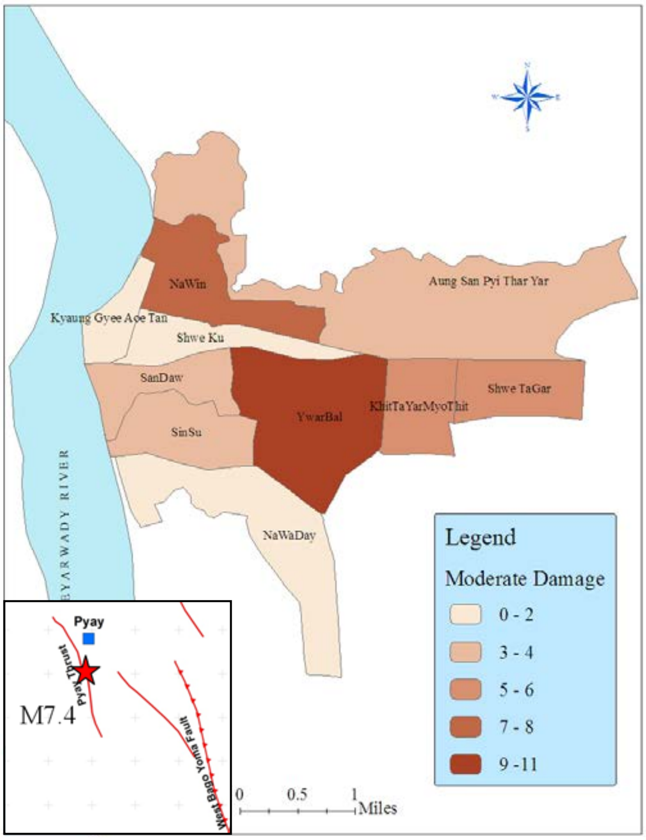

Figure B-18 Moderate Damage of Brick Masonry Buildings in Pyay by Scenario Earthquake

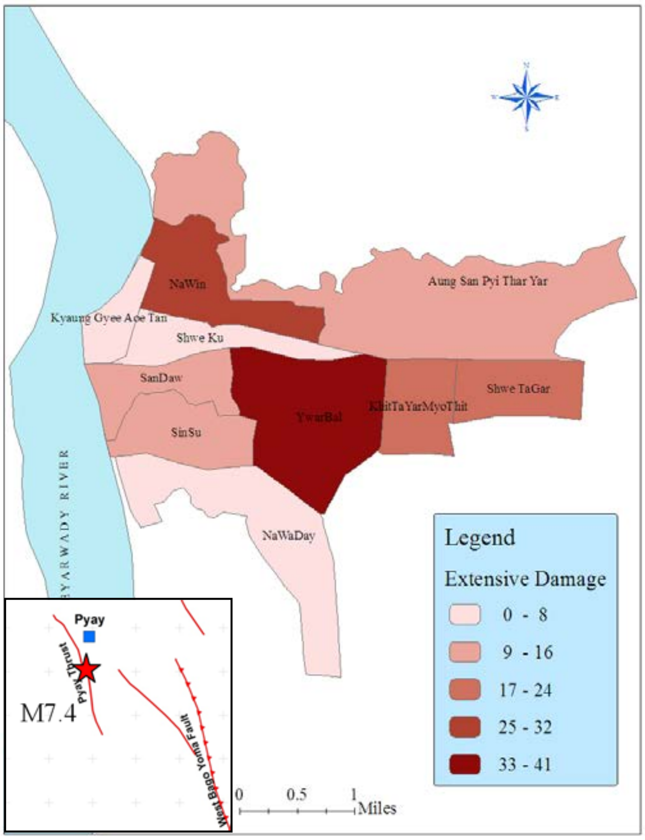

Figure B-19 Extensive Damage of Brick Masonry Buildings in Pyay by Scenario Earthquake

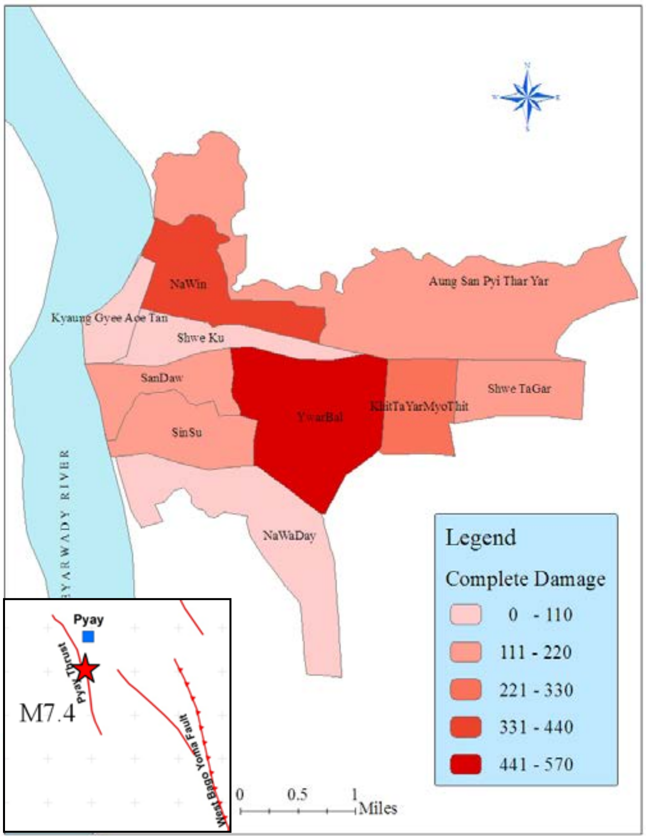

Figure B-20 Complete Damage of Brick Masonry Buildings in Pyay by Scenario Earthquake

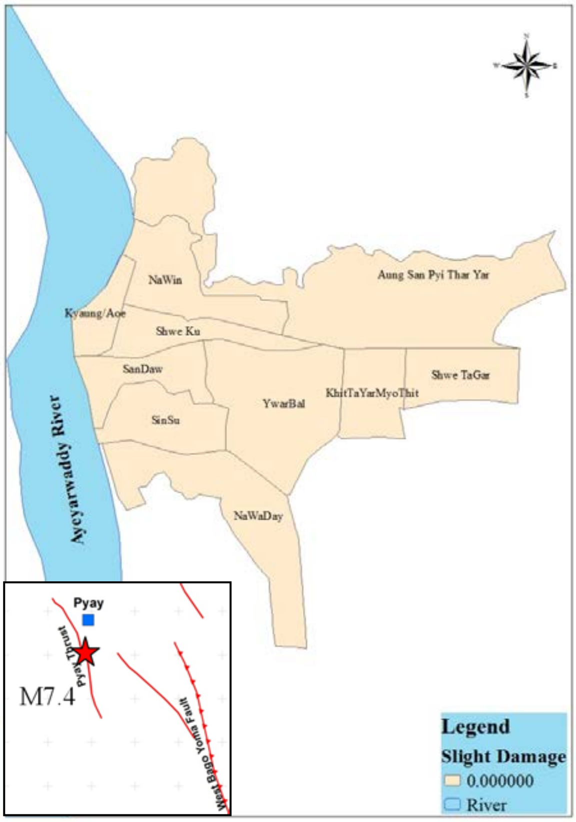

Figure B-21 Slight Damage of Mix-used Buildings in Pyay by Scenario Earthquake

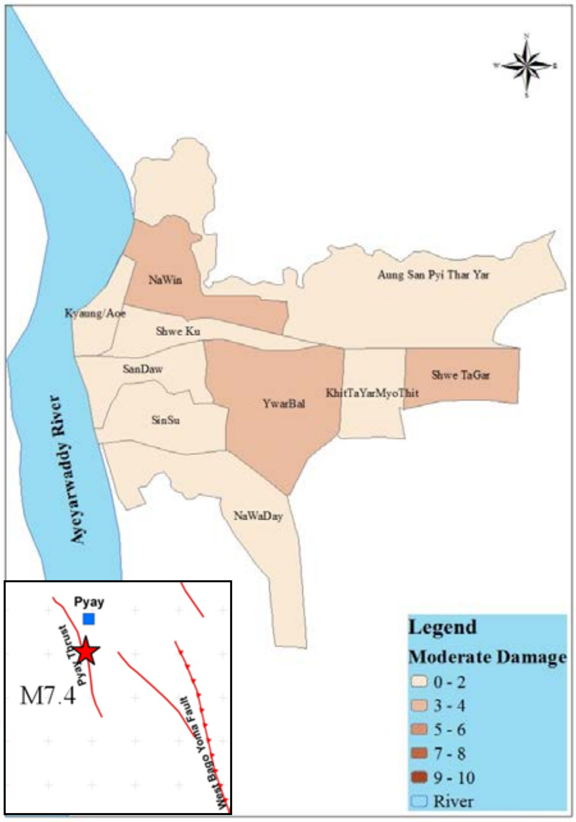

Figure B-22 Moderate Damage of Mix-used Buildings in Pyay by Scenario Earthquake

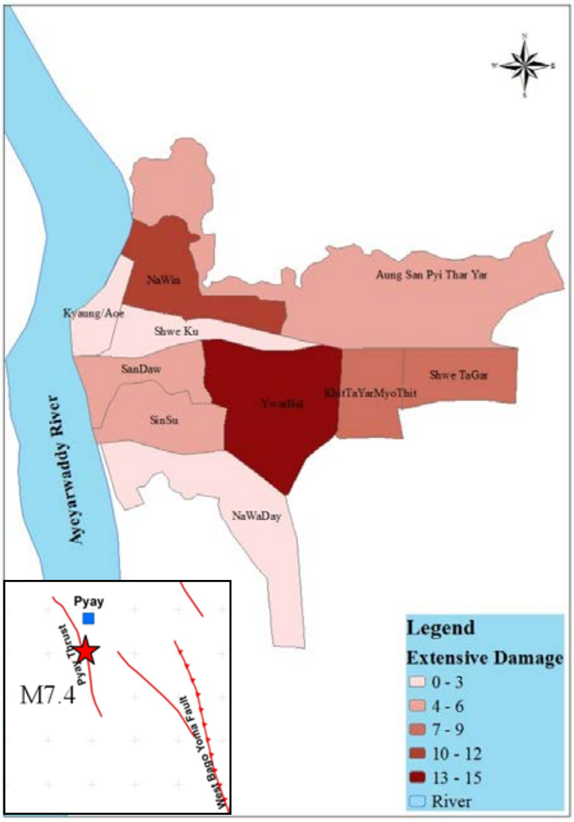

Figure B-23 Extensive Damage of Mix-used Buildings in Pyay by Scenario Earthquake

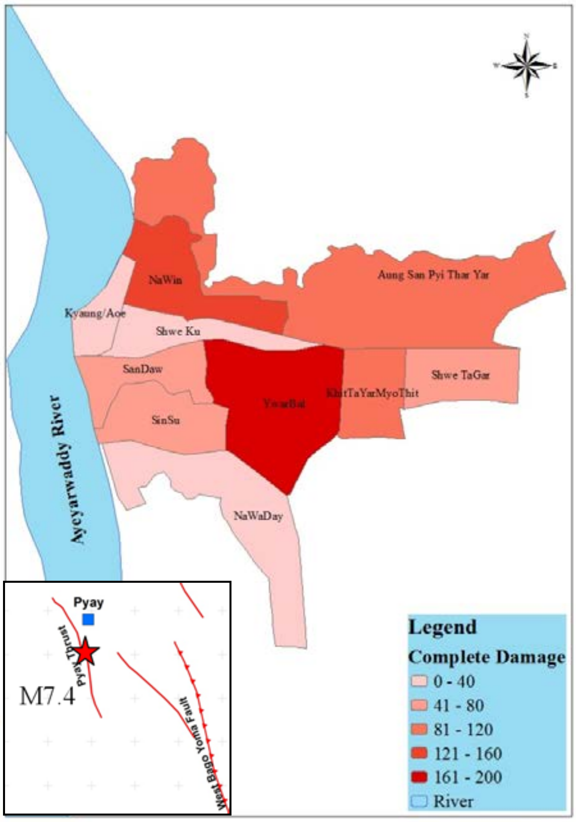

Figure B-24 Complete Damage of Mix-used Buildings in Pyay by Scenario Earthquake

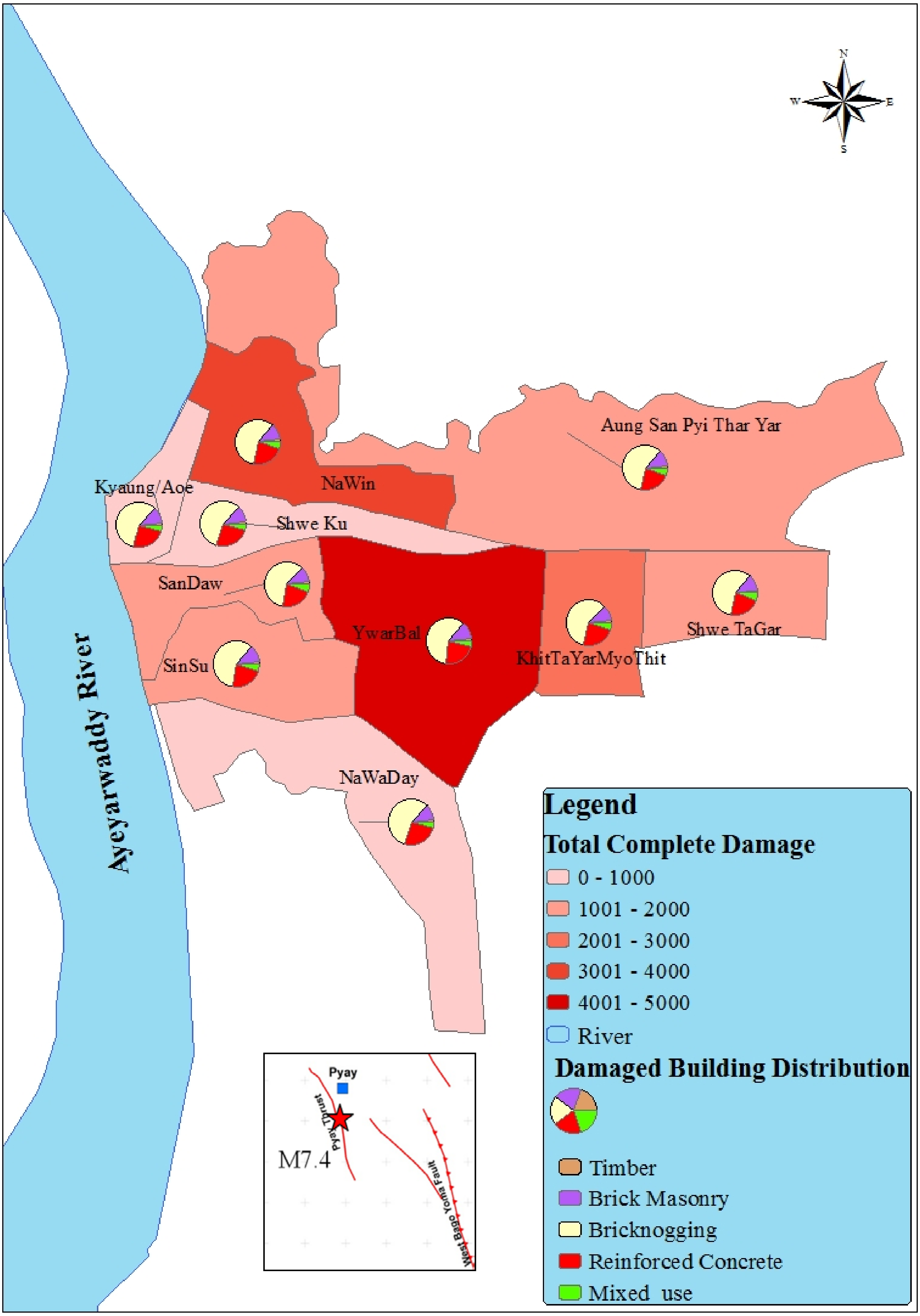

Figure B-25 Complete Damage by Structural Type

REFERENCES

1) HAZUS - MH MR 5 Technical Manual, Multi-hazard Loss Estimation Methodology, Earthquake Model, Department of Homeland Security, Federal Emergency Management Agency, Mitigation Division, Washington, D.C.
2) HAZUS - MH MR 5 User’s Manual, Multi-hazard Loss Estimation Methodology, Earthquake Model, Department of Homeland Security, Federal Emergency Management Agency, Mitigation Division, Washington, D.C.
3) Developing Probabilistic Seismic Hazard Maps of Pyay, Bago Region, Myanmar Report, Myanmar Geo-science Society, December 2015