Development of Damage Rate and Damage Index Functions for Brick-nogging and Wooden Buildings in 2012 Thabeikkyin Earthquake

Nan Pawt Sai Awar, Dr. Kyaw Moe Aung

Abstract—**A large earthquake had occurred on 11 November 2012, and many houses are severely damaged by the strong ground motion. For every earthquake, structures need to be surveyed in terms of building types, vulnerability and the degrees of damages. Buildings with different types of structures are damaged with various damage patterns and damage grades. So field investigation is important and it should be made as soon as possible after a high intensity earthquake occurred. In this paper, damage patterns and damage grades are proposed for brick-nogging and wooden buildings to classify building damaged without many difficulties. This paper also discusses the damage rate function to estimate the percentage of buildings damaged in different ground motions and the damage index function to know the damage degree of individual building.**

Keywords— **field investigation, damage patterns, grades, damage rate function, damage index function.**

I. INTRODUCTION

Myanmar is one of the earthquake prone countries. As it is situated on the boundary of the Alpine-Himalayan earthquake belt, there is always the seismic risk. In addition to this, the Sagaing fault is one of the great strike-slip faults of Southeast Asia, bisecting Myanmar from North to South. It is also the major right-lateral fault between the Sunda and Burma plates with the fault slip rate of 18 mm/yr. So Myanmar often suffered from earthquakes that sometimes caused great loss of human lives and damage to many historical buildings.

Thabeikkyin earthquake (Mw 6.8) has occurred 25 km away from Thabeikkyin Township, Mandalay Region in Myanmar. According to the trip report from the Myanmar Earthquake Committee [6], it happened because of the sudden movement of the Sagaing fault on 7:42 A.M. (local time) of November 11, 2012 and epicenter at 95.883°E, 23.014°N, 9.9 km (depth), that is 72.42 km far from Northern part of Shwebo Township, Sagaing District, Myanmar.

Structures need to be surveyed in terms of different types, the vulnerability of typical structures and the different scales of damaged within each building type. It is necessary to record the various types of buildings that were damaged to a lesser or greater degree. In this study, typical damage patterns due to earthquake and damage grades (heavy, moderate and slight)

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are proposed for single and two storey brick-nogging and wooden buildings by using field investigation and the recorded photographs. Therefore, it can easily be classified the damage degrees of each building without many difficulties even non professional. From this, damage rate function and damage index function are developed to evaluate the percentage of buildings damaged and the damage degree of individual building in different ground motions.

II. SURVEYED AREAS

The affected areas of 2012 Thabeikkyin earthquake are Mandalay, Inwa, Amarapura, Sagaing, Thabeikkyin, Kyauk Myaung and Singu in Mandalay District and Sagaing District. Especially Thabeikkyin Township, Kyauk Myaung Township and Singu Township had severe damaged. Field investigations have been carried out Twin Nge village, Ma Lae village, Thabeikkyin Town, Kyauk Myaung Town, Ma Lar village and Singu Town. These are the most affected areas during earthquake.

During field survey, the structural types of buildings were classified as R.C, brick-nogging, masonry and wooden buildings. We made preliminary field survey on 29 May and 11 June with some master students from Department of Civil Engineering, Mandalay Technological University in 2014. During this survey, we made visit to the General Administrative Office in the Thabeikkyin Township and collected the recorded photographs and the damage statistics data such as the numbers of buildings that partially collapsed and totally damaged in this township. Fig. 1 and Fig.2 show the location of epicenter and intensity of earthquake affected areas.

According to the preliminary investigation and recorded photographs, it can be seen that the most damaged structural type of building was brick-nogging (wooden frame with brick walls). Wooden building was the second most damaged structural type. Other structural types of buildings such as R.C buildings and masonry buildings also damaged but they are not so much in number compared with brick-nogging and wooden. They can also be classified as residential buildings and non-residential buildings such as governmental offices, hospital (including dispensaries), school and religious buildings by the usage of buildings. Fig.3, Fig.4 and Fig. 5 show some damage buildings after Thabeikkyin Earthquake.

Fig.1 Location of epicenter and main affected areas of the earthquake
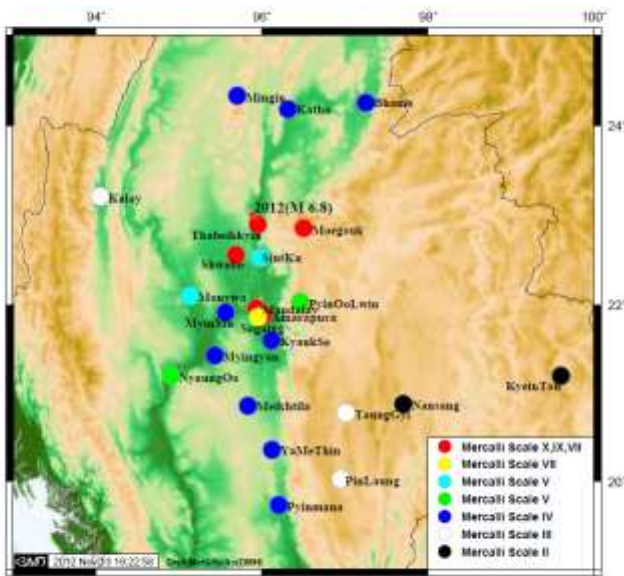
Source: Department of Meteorology and Hydrology, Myanmar
Fig. 2 Intensity scales of earthquake affected areas

Fig. 3 Collapse of masonry walls in single-storey governmental office

Fig.4 Collapse of masonry walls in two-storied residential building

Fig. 5 Failure of veranda in wooden residential building

III. DAMAGE PATTERNS AND GRADES

During earthquake, masonry dwelling houses generally shattered though portions of the walls were left standing sometimes. In some extreme cases, two-storied houses appeared to have been literally hurled to the ground, falling almost flat in low heaps bricks, plaster and splintered beams shattered. Foundations of heavy column were cracked and shifted. In some areas, masonry buildings, all of which were damaged, and some almost completely destroyed. The brick foundations of the timber posts supporting the houses were badly cracked horizontally [1]. In this study, damage patterns of brick-nogging buildings and wooden buildings are categorized by paying attention to damages of buildings on the basis of recorded photographs in the 2012 Thabeikkyin earthquake and responses of local people in the questionnaire survey. The damages are also arranged for three damage grades (slight, moderate and heavy) to classify the damage levels based on EMS-98 [3]. Each damage grade depends on the range of damage suffered from each building. The damage pattern of each building is studied on the facts such as the location of damaged members, the range of damage in these members and the structural type according to the recorded photograph. Damages were classified to single storey brick-nogging building into five types of damage patterns in the previous study [10]. We modify it in this study. Table I illustrates typical damage patterns and damage grades of brick-nogging buildings and wooden buildings.

TABLE I: Damage Patterns and Damage Grades of Brick-nogging and Wooden Buildings
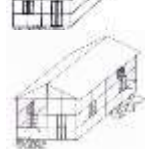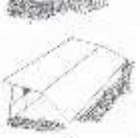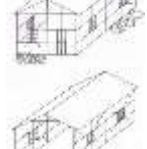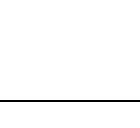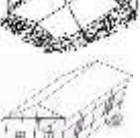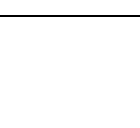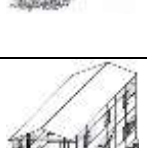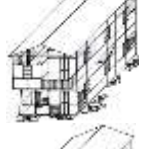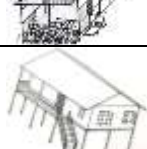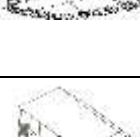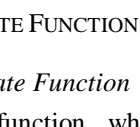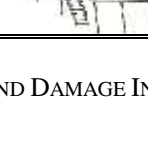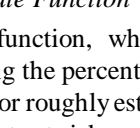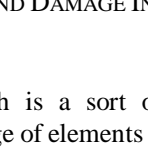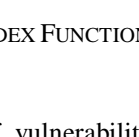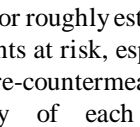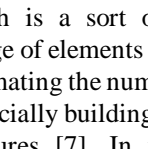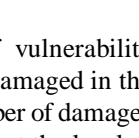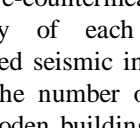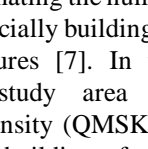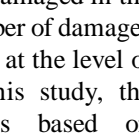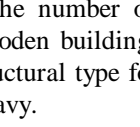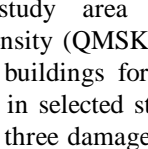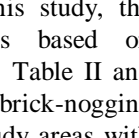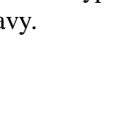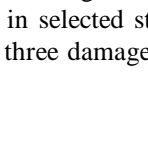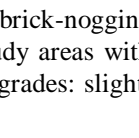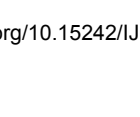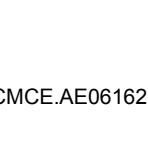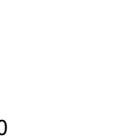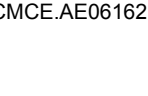
Structural types	Damage grades		
	Slight	Moderate	Heavy
Brick-nogging (one storey)			
Brick-nogging (two storey)			
Wooden			

IV. Damage Rate Function and Damage Index Function

A. Damage Rate Function

Damage rate function, which is a sort of vulnerability function describing the percentage of elements damaged in the area, is available for roughly estimating the number of damages to regional elements at risk, especially building, at the level of administrative pre-countermeasures [7]. In this study, the seismic intensity of each study area is based on questionnaire-based seismic intensity (QMSK). Table II and Table III show the number of buildings for brick-nogging buildings and wooden buildings in selected study areas with respect to the structural type for three damage grades: slight, moderate, and heavy.

TABLE II: Summary of Building Damage For Brick-nogging Buildings

Location	Number of Buildings				
	No Damage	Slight	Moderate	Heavy	Total
Kyauk Myaung	13	68	56	6	143
Singu	32	95	64	17	208
Malar and Makauk	6	56	35	14	111
Thabeikkyin	6	6	21	14	47
Twin Nge	7	35	80	10	132
Malae and Pzigyi	3	15	48	44	110

TABLE III: Summary of Building Damage For Wooden Buildings

Location	Number of Buildings				
	No Damage	Slight	Moderate	Heavy	Total
Kyauk Myaung	298	51	12	5	366
Singu	148	127	18	6	299
Malar and Makauk	304	102	2	8	416
Thabeikkyin	195	37	27	7	266
Twin Nge	207	53	45	29	388
Malae and Pzigyi	195	37	27	7	334

The curves of the damage rate functions of brick-nogging buildings and wooden buildings are constructed using the damage ratio of buildings in each location and the estimated MSK seismic intensity by questionnaire survey. The function is generally described with the following cumulative normal distribution function.

$$F(x) = \phi(\frac{x - \mu}{\sigma}) \tag{1}$$

where, $F(x)$ means damage rate in damaged area, ϕ is the standard normal distribution and μ and σ are the mean and standard deviation of x. The two parameters of the distributions, μ and σ are determined by the least square method on normal probability plotting paper.

Fig. 6 and Fig. 7 show the damage rate curves for brick-nogging buildings and wooden buildings.

TABLE IV: Parameters of Proposed Damage Rate Functions

Damage Grades	For Brick-nogging		For Wooden	
	Average (μ)	Stand. Dev. (σ)	Average (μ)	Stand. Dev. (σ)
Heavy	7.6	0.72	7.5	1.0
Moderate+	6.6	0.8	6.85	1.0
Slight+	5.45	0.8	5.8	0.9

Fig. 6 Damage rate function of brick-nogging buildings

Fig. 7 Damage rate function of wooden buildings

B. Damage Index Function

The damage index function is a function capable of calculating the damage state (i.e. damage index) of individual building under a certain ground motion severity represented by the intensity or peak ground velocity. Damage index function can express the seismic structural damage state of individual building. S. Okada and N.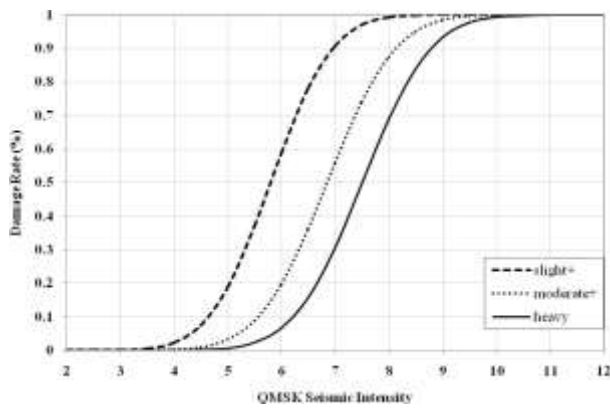 Takai [5] gave the numerical scale of damage degree defining from 0 (no damage) to 1.0 (total collapse) with some visualized damage patterns of buildings so as to help field investigation to classify building damaged without a gross error [7]. Table V shows the comparison between various damage grades. The damage grades of EMS-98 and the damage grades are compared in this study. For the damage index, the damage index scales are used from S. Okada and N. Takai [5].

TABLE V: COMPARISON BETWEEN VARIOUS DAMAGE GRADES

In this study, the damage indices are specified as slight (0.0 to 0.3), moderate (0.3 to 0.6) and heavy (0.6 to 1.0). The damage index function is the inverse function of the damage

rate function [7]. The seismic intensity affecting the damage grades can be obtained at arbitrary damage rates (1%, 20%, 40%, 60%, 80% and 99%) in this study. The damage index functions are obtained by fitting the following cumulative probability distribution with the Weibull density function.

$$F(x) = 1 - e^{-\left(\frac{x}{\eta}\right)^{\beta}} \qquad (2)$$

where, $F(x)$ means damage index, x is an index of seismic intensity, β and η are parameters of the Weibull distribution. These two parameters of the distribution are determined by Weibull distribution plotting paper.

Table VI describe the parameters of damage index function for brick-nogging buildings and wooden buildings. Fig. 8 and Fig. 9 show the damage index functions of brick-nogging buildings and wooden buildings.

TABLE VI: PARAMETERS OF PROPOSED DAMAGE INDEX FUNCTIONS

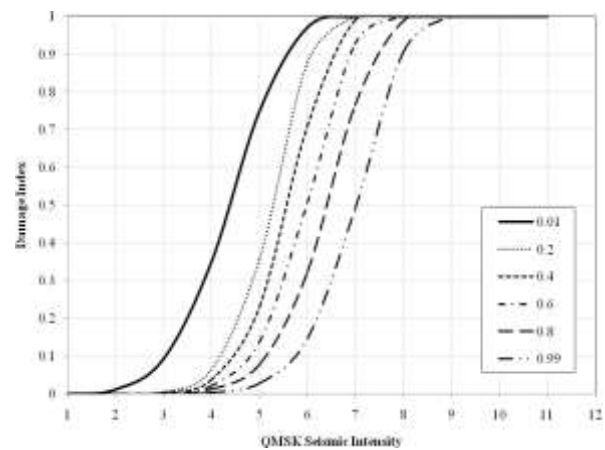| for brick-nogging buildings					
Damage rate (%)	0.01	0.2	0.4	0.6	0.8	0.99
η	4.7	5.5	5.85	6.25	6.7	7.3
β	5.22	8.5	8.5	8.5	8.5	9.4
for wooden buildings					
Damage rate (%)	0.01	0.2	0.4	0.6	0.8	0.99
η	4.9	6.8	7.6	8.1	9.1	11
β	5.53	5.53	5.53	5.875	5.53	5.875

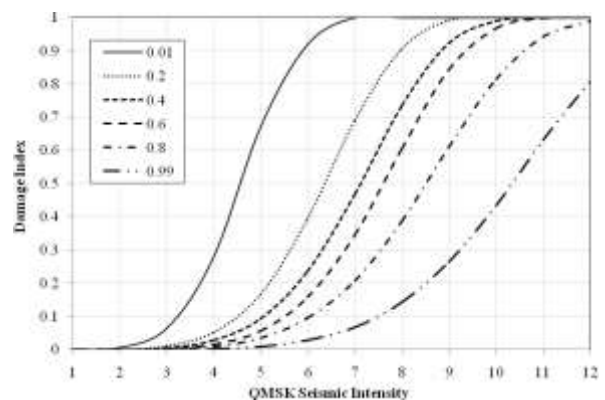Fig. 8 Damage index function of brick-nogging buildings

Fig. 9 Damage index function of wooden buildings

V. CONCLUSION

In this paper, the damage patterns of brick-nogging and wooden buildings could be categorized by paying attention to damages of buildings on the basis of recorded photographs in the 2012 Thabeikkyin earthquake. Damage grades are also specified with damage patterns based on EMS-98. According to the damage patterns and damage grades, the damage levels of buildings can easily be classified without difficulties. From this study, the damage rate functions describing the percentage of damage in a region are obtained to estimate the probability of percentage of damaged buildings for an assumed seismic intensity. The damage index functions capable of calculating the damage state of each building are also proposed under a certain ground motion severity. The same functions for other structural types of buildings can be obtained by following the above methods.

ACKNOWLEDGMENT

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