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THE GEO-DISASTER MITIGATION MEASURES IN MYANMAR

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Abstract

Myanmar has frequent geological disasters including earthquakes, tsunamis, landslides, and subsidences in karst area. Myanmar indeed is an earthquake-prone area as it lies in one of the two main earthquake belts of the world, known as the Alpide Belt that extends from the Mediterranean through Turkey, Iran, Afghanistan the Himalayas and Myanmar to finally Indonesia. Therefore, Myanmar is vulnerable to hazards from moderate and large magnitude earthquakes, including tsunami hazards along its long coastal areas.

The seismotectonics of the region indicate that earthquakes in Myanmar mostly originates along an active subduction zone (Andaman Megathrust Zone) in the West and along a large active transform fault zone (Sagaing Fault Zone) in the middle part of the country. Local historic records and legends also confirmed the fact that intermittent jerks along these major active faults have caused the majority of earthquakes in Myanmar. These seismotectonic processes are still going on. Along these fault zones stand many large urban cities where thick populations live in. Liquefaction is a very considerable factor according to the past events in the water saturated area near the fault zones.

Geomorphologically, Myanmar has two mountainous provinces: namely, the Western Ranges and the Eastern Highland. These provinces have inherently unstable nature among the areas of the country. The steep slopes, unstable geologic conditions and heavy rains combine together to make the mountainous regions one of the most hazard-prone areas in Myanmar. Landslides frequently happens in these regions, disturbing the connection roads and infrastructures rather than rural houses. Moreover, there has been an increase in human settlement in hazard-prone areas as a result of rapid population growth, as well as improvement in accessibility by road and the onset of other infrastructure development. Consequently, natural and man-made disasters are on the increase and each event affects people more than before. Even in central low land between the two mountainous ranges, landslide features occur along the bank of Ayeyarwady River and its tributaries.

There were also records of moderate tsunami generated by two large magnitude earthquakes, which originated in the Andaman-Nicobar Islands. Of course, the tsunami generated by the giant 2004 Sumatra Earthquake also caused moderate causalities in some parts of the Myanmar coast. Thus, it is evident that Myanmar is vulnerable to disaster from moderate and large tsunamis along its long coastal line.

To mitigate loss of lives and damages of properties, the Natural Disaster Mitigation Committee of Myanmar has been formed since 2004. Moreover, Seismic Hazard Zonation Map of Myanmar has already been prepared with the collaboration of engineering geologists, geoscientists and engineers since 2006. During the year of 2006 to 2008, the Myanmar Geosciences Society (MGS) in collaboration with MEC has prepared the preliminary deterministic seismic zonation maps for four seismically hazardous cities.

Although modern seismological instruments and technical improvement are very essential, earthquake resistant design code shall be enhanced by the cooperative works among the scientists and engineers from various organizations. Landslide po-

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tential map and tsunami inundation map are going to be established this year. Moreover, to increase the awareness of the geo-disaster, education and knowledge have been given to those who live in hazardous-prone areas by the collaboration of DMH, RRD, MES, MGS, ADPC and Universities in Yangon. Besides, landslide mitigation technology applied in Myanmar and construction of tsunami shelter in coastal areas are also discussed in this paper.
Keywords: *Earthquake, tsunamis, active fault, landslide, liquefaction*

1 Introduction

In recent times, Myanmar has experienced large magnitude earthquakes and related hazards, frequent landslide phenomena and very rare occasion of sink-hole and karst formation. Tectonically and geomophologically, Myanmar can be subdivided into three provinces (Maung Thein, 1993): namely, the Western Fold Belt (WFB) in the West, the Central Lowland (CL) in the middle, and the Eastern Highland (EH) in the East. Geologically, the WFB consists mostly of very thick sequence of the flysch type sedimentary rocks and tectonic mélange of basic and ultrabasic rocks and exotic limestone in the form of ophiolite suite resulted by the subduction of the Indian Plate underneath the BWurma Plate along the Bengal tectonic boundary. Continued collision between these two plates also leads to the formation of high mountain arc in the East and Northwest parts of Myanmar. Further East is the Eastern Highland which is a part of the Shan-Thai Block (a large tectonic domain that connects the Pacific tectonic plate) and composed mainly of older rock groups containing plateau limestone and metamorphic complex. The fertile alluvial plain is the Central Lowland, intermittently cropped out by the mountain range and hills running in North-South direction and also enhanced by Mount Popa, a dormant volcano in its central part. A large active fault, the Sagaing Fault (Win Swe, 1981) is passing through the Eastern margin of this province. As an order of importance, this paper will focus particularly on the earthquake and its related hazards and some landslide hazard and their mitigation measures.

2 Research Methods

To identify the geo-hazards of the whole country, tectonical, geomorphological, historical events of the disasters, satellite images of the country and its environments, GIS data, aerial photographs of hazard-prone areas and post disaster survey have been conducted. Taking consideration upon these evidences, the deterministic seismic zone map of Myanmar and major cities, the potential area of landslides and tsunamis have been developed up to now.

Seismicity and seismotectonics of the region

Myanmar indeed is earthquake-prone as it lies in one of the two principal earthquake belts of the world: the Alpide Belt. The seismotectonics of the Myanmar region is shown in Figure 1 (Thein and Swe, 2008). Earthquakes in the Myanmar region have originated from two main causes: (1) the subduction (with collision only in the North) of the northward moving India Plate underneath the Burma Plate at an average rate of 4 to 6 cm/yr along the Andaman Mega-thrust Zone; (2) the northward movement of the Burma Plate from the spreading centre in the Andaman Sea at an average rate of 2.5 to 3 cm/yr.

Very large over-thrusts along the Western Fold Belt have resulted from the former movement and the Sagaing and related faults from the later movement. Intermittent jerks along these major active faults have caused the majority of earthquakes in Myanmar. These seismotectonics processes are still going on. The earthquakes that are generated by sea-floor spreading in the Andaman Sea, however, are mostly small to moderate in magnitude and shallow-focused.

The historical and seismic records show that in addition to some major historical earthquakes in the distant past, there had been at least 17 large earthquakes with M 7.0 within the territory of Myanmar in the past 170 years (Thein and Swe, 2008). Some recorded large historical earthquakes are listed in Table 1 (Myint and Swe, 2006).

Table 1: List of some strong earthquakes in Myanmar

No	Date	Epicentre Lat N Long E	RM	Remarks
1	2 April 1762	21° 30′ 92° 00′	7.0	Sittwe Area; very destructive violent earthquake felt over Bengal, Rakhine up to Calcutta (Kolkata)
2	23 Mar 1839	21° 42′ 96° 00′	8.0	Amarapura; almost the whole city destroyed, the ground surface broken; the river's flow was reversed for some time; Mingun Bell fallen down; 300 to 400 killed
3	24 Aug 1858	19° 00′ 95° 00′	7.5	Thayet (Pyay); houses and tops of pagoda collapsed; felt Innwa, Sittwe and Yangon
4	23 May 1912	21° 00' 97°00'	8.0	North of Taunggyi, serious landslides; foreshock noted on 18 May 1912
5	06 Mar 1913	17° 00' 96°50'	7.0	"Hti" (decorative umbrella) of Shwe Maw Daw Sedi in Bago grounded
6	05 Jul 1917	17° 00' 96° 50'	7.0	"Hti" of Shwe Maw Daw Sedi in Bago grounded
7	19 Jan 1929	25° 90' 98° 50'	7.0	Brick buildings destroyed in Htaw Gaw
8	08 Aug 1929	19° 25' 96° 25'	7.0	Railway lines bent at Swa
9	16 Dec 1929	25° 90' 98° 50'	7.0	Landslides at Htaw Gaw
10	05 May 1930	17° 00' 96° 50'	7.3	Many houses destroyed, and 500 killed in Bago; Some houses destroyed, and 50 killed in Yangon
11	03 Dec 1930	18° 00' 96° 50'	7.3	Some houses destroyed, about 30 killed in Phyu
12	27 Jan 1931	25° 60' 96° 80'	7.6	Brick building collapsed, landslides at Karmine
13	12 Sep 1946	23° 50' 96° 00'	7.7	Pagodas collapsed at Tagaung, 32 houses destroyed, 380 acres of crop damaged
14	16 Jul 1956	22° 00' 96° 00'	7.0	Pagodas and buildings at Sagaing destroyed, about 40 killed, Sagaing bridge displaced slightly
15	08 Jul 1975	21° 50' 94° 70'	6.8	Many historical Pagodas destroyed, 2 killed near Bagan
16	05 Jan 1991	23° 48 ' 95° 98'	7.1	Landslides, ground cracks, sand blows, pagodas and buildings destroyed at Tagaung, Htigaint, Kawlin and Thabeikkyin
17	22 Sep 2003	19° 94' 95° 72'	6.8	Landslides, liquefaction and destruction of pagodas, some bridges in Taungdwingyi (7 persons killed)

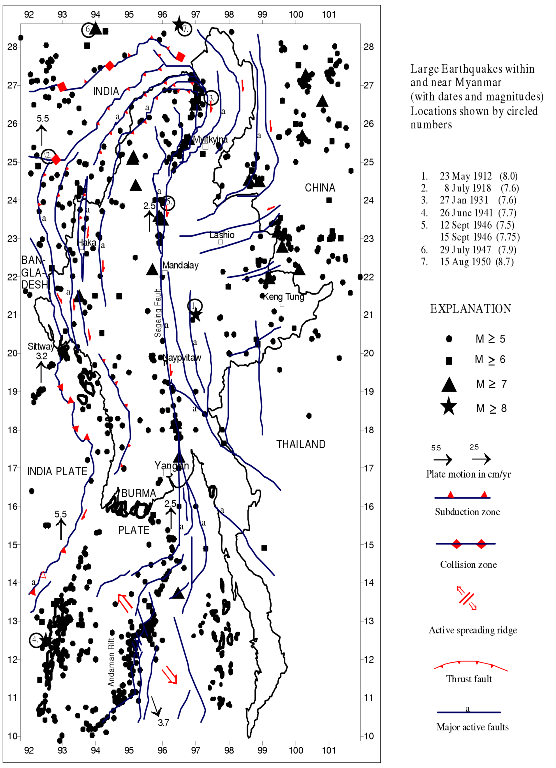

Figure 1: Seismotectonic map of Myanmar region

Figure 2: Collapse of primary school at Chezeaing village during Taungdwingyi earthquake

Figure 3: Settlement of school foundation due to liquefaction

Earthquake related hazards

Building collapse is a major hazard. The severe damages of the large magnitude earthquakes might affect mostly on the rural house since they are unengineered structures, even in the city where the old buildings existed. The population density tremendously increases in major cities; unfortunately, these large cities lie near or quite close to the major active faults in Myanmar (for an instance, the cities of Yangon, Bago, Taungoo, Napyitaw, Pyinmana, Kyaukse, Mandalay, and Myitkyina stand along the Sagaing Fault and Taunggyi City is near the Kyaukkyan Fault). At least ten million people are living on the Sagaing Fault region. Liquefaction is a collateral effect of large earthquakes that happened in the younger alluvial deposits consisting of loose silty and sandy soil. Past experiences from the Tagaung Earthquake (M 7.1, 5 Jan, 1991) and the Taungdwingyi Earthquake (M6.8, 22 Sep 2003) (Figures 2 and 3) indicated that many rural houses were sinking down to the earth, the foundations of the ancient stupas were tilted and many paddy fields were damaged by sand boiling. Many cities in the central part of Myanmar are situated on the alluvial plain which are highly vurnerable to liquefaction when large magnitude earthquake happens.

Tsunami causes and characteristics in Myanmar

There were also records of moderate tsunami generated by two large magnitude earthquakes which originated in the Andaman-Nicobar Islands. These are the M 7.9 Car Nicobar Earthquake (31 December 1881) and the M 7.7 Andaman Island Earthquake (26 June 1941). The tsunami generated by the giant 2004 Sumatra Earthquake also caused moderate damage (Figures 4 and 5) in the delta region and the southern Myanmar Coast. The causality is also comparatively lower than the other countries around the Indian Ocean (Table 2). Thus, it

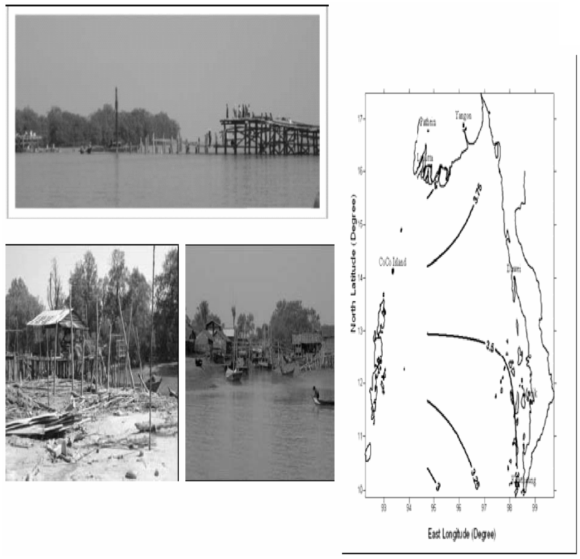

Figure 4: Record of damage and casualties in 2004 Tsunami at the Ayeyarwady Delta Region

Figure 5: Record of damage and casulities in 2004 Tsunami at the Ayeyarwady Delta Region

is evident that Myanmar is vulnerable to hazards from moderate and large tsunamis along its long coastline. In view of these, it is necessary to assess the earthquake and tsunami hazard potential along the Myanmar coastal area.

After 2004 Tsunami, scientists from Geological Survey of Japan could find at least three large tsunami records in the Bay of Bengal and Adman Sea region during 2800 years time span. The last one before 2004 was dated as of 550 to 700 years ago (Jankaew et al., 2008), after studying peaty soil in the sand sheets of Phra Thong, 125 km north of Phuket, Thailand. Therefore it can be assumed that big tsunami might occur in about 500 to 700 years.

Again, Chandra (1978) (in Satyabala, 2003) located the epicenter of 1762 earthquake at 22 N and 88 E, i.e., north of Kolkata. On the other hand, Ganse and Nelson (1982) located the epicenter at 22 N and 92 E, i.e. east of Chittagong where the damage was severe. In case of the epicenter was on the land, the possibility of tsunami is very less. Considering the two different views on the epicenter of 1762 Earthquake, it is difficult to ascertain whether the Earthquake generated tsunami or not.

Recent paleoseismological studies by the joint Myanmar-Japanese teams in the northern Rakhine Coast (Aung et al., 2008) revealed the presence of at least three raised marine terraces with radioactive carbon dates result ranging from 1400 BC to 1860 AD, and indicate that there were at least three great earthquakes (including 1762 earthquake) in that region in the past 3400 years.

Landslide causes and characteristics in Myanmar

Geomorphologically, Myanmar has two mountainous provinces: namely the Western Ranges and the Eastern Highland. These provinces have inherently unstable nature among the areas of the country. The steep slopes, unstable geology, and intense monsoon rains combine to make the mountainous regions one of the most hazard-prone areas in Myanmar. More recently there has been an increase in human settlement of hazard-prone areas as a result of population pressure, as well as improvement in accessibility by road and the onset of other infrastructure developments. Consequently, natural and man-made disasters are on the increase and each event affects people more than before. Besides, the major river of Myanmar, River Ayeyarwady flows from North to South in the central lowland. Because of the flooding and erosion, the landslides occur along the banks of this river and its distributaries.

Due to the rising of groundwater in monsoon, the saturation of the soil increases hence destroys the capillary tension in soil and reduces its cohesion. This process leads to high pore water pressure in slopes. Again due to the troublesome materials in slopes, liquefac-

Table 2: Official damage and deaths for Myanmar in 2004 tsunami

State/division township	Village	Households	Affected population	Injured	Missing	Deaths	Properties damaged
Ayeyarwady division							
1. Labutta	7	337	1,138	41		25	99 boats, 8 schools, 4 rice mills
2. Ngaputaw	9	108	1,007			5	19 boats, 1 bridge, 2 pagodas
3. Bogalae (urban area)						1	wall collapsed
Rakhine state						22	
Tanintharyi division	7	92	447			8	44 boats, 3 warehouse, 1 bridge
Total	23	537	2,592	41	3	61	162 boats, 8 schools,4 rice mills,3 pagodas, 2 bridges, one wall

tion, expansive nature, subsidence and sensitive phenomena occur in mountainous regions of Myanmar. Soil erosion is another problem which is exaggerated with heavy rain fall and deforestation. The uncontrolled flow of rainwater on slope surface washes out soil and boulders and threaten the people living along the base of the hilly regions in Myanmar. Because of the rapid urban development and increasing the traffic flow, mass scale construction of houses and heavy structures on entire hill may cause landslides.

Soluble rocks with solution cavity (Figure 6) in Karst areas also cause planar sliding and subsidence. Earthquakes have acted as triggers to many landslides and ground failures in some parts of earthquake-prone areas such as in Pyinoolwin area, Tagaung area and Taungdwingyi area.

Various sizes of landslides frequently occur in mountainous regions of the Western Ranges (Figure 7) and some localities in the Eastern Highland, especially along the western flank of the Tanintharyi Ranges. The collapses of river bank are found along the Ayeyarwady River and its distributaries. The Western Ranges has experienced many types of landslides and earth movement, i.e. rock falls, rock slides, soil avalanche and mud flows of various scaled due to the wedge failure, plane failure, toppling, and circular failure. The direct impact of landslide in this region is the damage of the infrastructure rather than human settlement because these areas are sparsely populated (Lain 1983).

Figure 6: Karst Formation Near Pwekauk Chaung in Eastern High Land

In the Eastern High Ranges, landslides of all types were occurred along the western flank of the Kachin, Shan and Tanintharyi Ranges. In Tanintharyi area, some rural houses and primary school were buried in the debris materials during the rainy season in 1999.

In 2001, subsidence events were occurred in Nansang area due to the Karst formation. Any impacts were not observed due to these events. However, landslides in Mogok have been observed as some types of mass movements and caused the loss of lives and properties in June, 2008. Some historical landslides events are

Table 3: List of some landslide events in Myanmar

Year	Location	Name and Type	Triggering Process	Impact
1912	North of Taunggyi	Maymyo landslide	Earthquake	serious landslides and ground cracks
1946	Tagaung	Landslides	Earthquake	380 acres of crop damaged
1991	Tagaung	Landslides	Earthquake	some buildings destroyed
1999	Along the western slope of the Tanintharyi Ranges	Landslides	Torrential rain	buried some villages
2001	Nansang	Subsidence	Heavy rain	two circular graven about 50 feet diameter appeared
2003	Taungdwingyi	Landslides	Earthquake	some slopes and rail roads along the western flank of Bago Yoma failure
2004	Kalewa-Kale road	Chaungkyin Landslides	Heavy rain	bridges and about 30 km of the main road destroyed
2008	Mogok	Mogok Landslides	Heavy rain and excavation	about 11 people killed
2009	Kyauktaw-Ann road	Kyauktaw landslides	Heavy rain	about 120 km of the main road destroyed

Figure 7: Multi-landslide scars occurred in Western Ranges

shown in Table 3 according to their characteristics.

3 Analysis of the Results of the Research

3.1 Earthquake hazard potential areas in Myanmar

According to the facts mentioned above, the Seismic Zone Map of Myanmar has been developed in 2006 (Thein and Swe, 2006). As shown in Seismic Zone Map (Figure 8), five seismic zones are demarcated and named (from low to high), mainly following the nomenclature of the European Macroseismic Scale 1992.

3.2 Tsunami hazard locations in the country

Myanmar has a fairly long coastline of approximately 2,200 kilometers long. It consists of three main segments; namely, the Rakhine Coast in the northwest, the Ayeyawady Delta in the middle, and the Taninthayi Coast in the south.

The northern Rakhine Coast, adjacent to Bangladesh, consists of some large offshore islands, and the intervening areas between these and the coastline are marshy and partly covered with mangrove forests. This setting therefore provides partial protection from tsunami waves. However, the southern Rakhine Coast

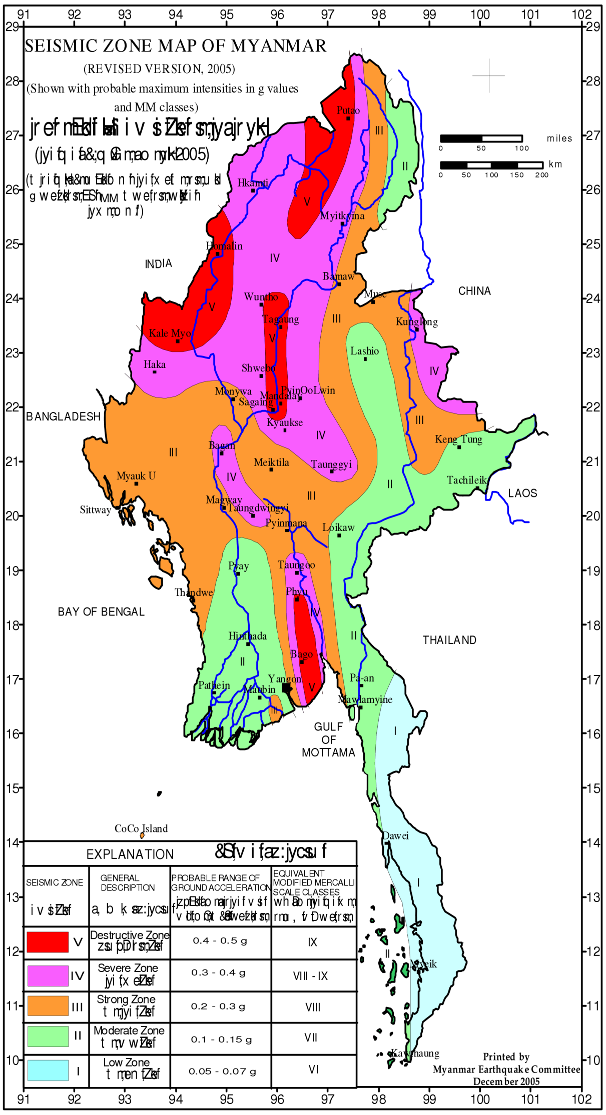

Figure 8: Seismic zone Map of Myanmar earthquakes on the known segments of the active faults and basement geology, three seismically active regions can be identified in Myanmar: (1) the northwestern region (part of the WFB); (2) the central lowland; and (3) the Shan Plateau-Yunnan Region.

generally is rocky and sandy with three popular resort areas. Thus, this part is comparatively more vulnerable to the tsunami hazard.

The Ayeyawady Delta is a large delta with wetlands and mangrove forests, thus providing partial protection from tsunami waves. The delta front is wide with shoals in some places, thus slowing down the tsunami speed. Immediately to the east lies the mouth of Sittoung River which is a wide estuary that widens southwards to form the Gulf of Mottama.

The Taninthayi Coast consists of two geomorphic parts. The northern part is rocky and bare, but the southern part contains the Myeik (Mergui) Archipelago that consists of more than eight hundred islands which are sparsely populated, with human settlements mainly on the east coasts, i. e., in the shadow sides from tsunami waves. Moreover, the southern part is partially covered with mangrove forests, thus providing partial protection from tsunami waves. These factors indicate that the southern part is comparatively less vulnerable to the tsunami hazard.

With the reference to the seismic zone map and certain characteristics of the three segments of Myanmar coastline mentioned above, the probable earthquake and tsunami hazards along the Myanmar costal areas are summarized in Table 4.

3.3 Landslide potential areas in the country

Various sizes of landslides had frequently occurred in mountainous regions of Myanmar especially in the Western Ranges and some localities in the Eastern Highland. The Western Ranges has experienced all types of landslide and earth movement, i. e., rock falls, rock slides, soil avalanche and mud flows of various scaled. The direct impact of landslide in this region is the damage of the infrastructure rather than human settlement because these areas are sparsely populated. In September 2004 in the middle of rainy season, there was a large scale landslide (and earth movement) happened along the Kale-Kalewa road near to the Kale City, the Sagaing Division of Myanmar. Bridges and main road of about 30 kilometers long were destroyed. Even a minor rock and soil slides can

Table 4: Probably earthquake and tsunami hazard along the Myanmar coastal areas

Costal Region	Area	Earthquake Hazard	Tsunami Hazard
Rakhine Coast	Northern part	Strong Zone with MMI 8	Moderate*
	Southern part	Moderate Zone with MMI 7	Moderate
Delta Area	Ayeyarwady Delta	Moderate Zone with MMI 7	Moderate
	Sittoung Estury	Moderate Zone with MMI 8-9	Moderate
Taninthayi Coast	Northern part	Moderate Zone with MMI 7	Moderate
	Southern part	Moderate Zone with MMI 7	Light**
*maximum run-up height = 4 m;		**maximum run-up height = 2 m	

Figure 9: Landslide found in Chaungkyin area

clog the road and it can take several hours to remove. Figures 9 and 10 show some record photographs of the Kale landslide in 2004.

One of the major rivers of Myanmar, River Ayeyarwady flows from North to South in the central low land. Because of erosion and flooding of the river, landslide hazards occur along the bank of this river and its distributaries.

4 Discussion on Geo-disaster Mitigation Measures in Myanmar

On the purpose of Protecting Life from Geo-Disasters, the Seismic Zone Map of Myanmar (2005) was prepared by a team led by Dr. Maung Thein during 2003 to 2005 with several detail observations and brainstorming. Tectonic activities in connection with earthquake information from external sources are applied

Figure 10: Serious landslides and rock- falls along Kale-Kalewa main road

in the development of the map (Maung Thein and Tint Lwin Swe, 2006), deterministically and some intuitively.

During the years of 2005 to 2007, the Myanmar Geosciences Society, in collaboration with the Myanmar Earthquake Committee (MEC), sponsored some graduate students of the Universities of Yangon, for the preparation of preliminary seismic micro zoning maps for four seismically hazardous cities. These are deterministic maps.

In the development of Building Code (Myint et al., 2007), the study of that of the other countries like Thailand, India, Indonesia and the UBC (Uniform Building Code of United States) are very helpful, but the background geological setting as well as the surface composition of geologic material, especially technical characteristics and distribution of rock and soil deposits of Myanmar, is quite different from that of other countries. For earthquake safety of buildings, seismic demand from various sources should be analyzed by means of ground motion attenuation models and used as a seismic coefficient which is then applied in calculating base shear of the structure. Earthquake ground motion and intensity levels can be obtained from the proper installation of network of the seismological stations covering well defined seismogenic sources.

However, the number of seismological stations in Myanmar is limited for acquiring earthquake information and establishing database and need to be upgraded not only instrumentation but also in technical concerns.

For application of seismic design code, levels of earthquake intensities are mainly based on the earthquake-zoning map. During the development of building code in Myanmar, the requirement of modern seismological instrumentation and technical improvement in the field of engineering seismology and earthquake engineering shall be enhanced by cooperative works among the scientists and engines from various organizations.

Education of non-technical people about earthquake and its related disasters is now being started by the collaboration of Department of Meteorology and Hydrology (DMH), Relief and Resettlement Department (RRD), Myanmar Engineering Society (MES), Myanmar Geosciences Society (MGS), Asian Disaster Preparedness Centre (ADPC) and Universities in Yangon.

Taking consideration upon the paleoseismological finding in northern Rakhine Costal Area and Bay of Bengal, the probable earthquakes and tsunami hazards along Myanmar costal areas, has been prepared by the members of MEC and this map is going to be established soon.

To mitigate the landslide hazards, local community plays an important role. Therefore, education of landslide for rural areas has been initiated by the collaboration of Ministry of Education, MES, MGS and ADPC.

To control slope stability, some technical methods such as excavation method, water management and drainage measure, structural support measure (rock-bolts, rock-anchor, retaining wall, and buttress), geotextile and river training measure are applied in Myanmar. Landslide potential map is also being prepared.

5 Conclusion

As Myanmar is an earthquake prone country, it has two important tectonic features and earthquake sources, one within Myanmar and the other in her neighbourhood to the West. These are the active Sagaing fault, trending North-South across the entire length of central Myanmar, and the Sunda subduction megathrust zone running through off-shore Southwest and West of the Myanmar coast and on-land to the West and Northwest of Myanmar. The Sagaing fault passes through the most populated areas of Myanmar where large cities have been built. Therefore, active fault studies with characterization of earthquake response spectrum on engineering structures and design code for buildings ; upgrading of the existing seismological stations; and then installation of some more modern-type seismological stations in some suitable locations, such as Hpa-an, Pathein, Bago, Pyinmana, Magway, Kalemyo and Muse are necessary.

Concerning tsunami hazard, the intensity in terms of run-up and the extent of the inundation was comparatively lower than the other countries around the Indian Ocean and the causality and damage was also lesser. For distance tsunami source (like Sumatra), Myanmar coastal areas have more time for preparation to escape from the killer waves. The records from 2004 Indian Ocean Tsunami show that the first arrival of the tsunami was at least three hours later than the time of earthquake happened. But for the near source tsunami (for instance, a large earthquake happened in the Andaman Island region and if it generates the tsunami), the delta region of Myanmar has only short duration for preparation. Therefore, it is prudent to install an effective tsunami warning system in the northern Bay of Bengal with international cooperation.

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