Seismic Risk Analysis for Critical Infrastructure: The Case Study of a Medical Center and its Supporting Systems in Yangon, Myanmar

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***Abstract*— Myanmar has a great strike-slip active fault called the "Sagaing Fault Zone" besides the Sumatra-Andaman Subduction Zone. Major cities (Yangon, Naypyitaw, Bago and Mandalay) are at risk along this fault. Recently, in 2012, Thabeikkyin earthquake with Magnitude of 6.8 caused collapse of many residential housings and ground failures near Mandalay. Therefore more attention should be paid for Yangon which has no large earthquakes since 1930 and is the largest not only in population but also in socio-economic activity. One of the most important concerns after an earthquake is to survive under any disastrous conditions. The medical care is requested not only for emergent injured people after an earthquake, but also for various types of patient and aged people from several weeks to longer periods. So medical center must be always functional before and after earthquake. For this purpose, medical buildings should be structurally resilient and also be functional for medical services by sustainable supply of electric power, water and any other delivery service which can be carried out by urban lifeline systems. This research is to investigate the structural vulnerability of hospital buildings and facilities, to assess the performance of urban lifeline systems and to check the operational capability of medical services in which surgical capability and life safety management method should be discussed. The water supply system is adopted as a typical lifeline system in Yangon in this study. One sample medical center in Yangon is adopted to carry out this analysis. Finally, the performance of medical services after the earthquakes can be assessed in a probabilistic manner.**

Keywords— *vulnerability assessment, performance, hospital building, lifeline system, medical service, fault.*

I. INTRODUCTION

Myanmar is earthquake-prone area and has many active faults as shown in **Figure 1**. Among them, Sagaing fault is a great strike-slip fault and passes through populated cities. This fault has the return period of 50 to 80 years. Yangon which is the biggest city and has highest density of population in Myanmar, is located at 50 km far from the epicentre along the Sagaing fault. It frequently experiences to earthquakes in various intensities.

In Yangon, most of the hospital buildings and their related supporting facilities were designed and built since the seismic design guideline had not been established. These structures are potentially vulnerable for future earthquakes and medical serviceability might be difficult to maintain in the minimum requirement level immediately after the earthquake.

One of the most important concerns after an earthquake is to survive under any disastrous conditions. The medical care is requested not only for emergent scene immediately after the earthquake, but also for various types of injured, patient and aged people from several weeks to longer periods. Therefore the functionality of hospital system after earthquakes is of vital importance.

Hospital system is supported by various supporting and lifeline facilities. The functionality of supporting system in a hospital has a considerable effect on the functionality of the main hospital buildings. The supporting system includes water supply system, electricity system and fire system. The water supply system and pipeline network which must be structurally resilient and functional after earthquakes should have as the same target performance levels as the main hospital buildings.

In the present water supply system of Yangon which has been operated over 100 years, all pumping in reservoirs and main transmission pipes have already aged and beyond its life span. As a result, almost 50% water leakage loss is estimated. Seismic design guideline, however, has not been established not only for pipes but also any supporting facilities related to the water supply system.

This research is to investigate the structural vulnerability of hospital buildings and facilities, to assess the performance of urban lifeline systems and to check the operational capability of medical services. Schematic illustration of study area is shown in **Figure 2**.

As a case study, among the hospitals in Yangon, Thingangyun (Sanpya) hospital (shown in **Figure 3.**) is selected depending on not only the medical requirements of the local people but also soft soil conditions in

Thingangyun Township. Site plan of the hospital including water supply system is shown in **Figure 4.**

In this study, according to the three earthquake levels of probability of exceedance 50%, 10% and 2% in 50 years such as Maximum Operational Earthquake (MOE), Design Basis Earthquake (DBE) and Maximum Considered Earthquake (MCE), the damage of buildings and water supply facilities can generally be three stages: Immediate Occupancy (IO), Level of Safety (LS) and Collapse Prevention (CP).

II. METHOD

Existing condition of site data, earthquake hazard data, structures data, water lifeline data are collected. The case study hospital was constructed in 1991 so the design of structures for existing condition is carried out without considering the seismic loading on the basis of older code ACI 318-99. Nonlinear static pushover analysis based on ATC-40 capacity spectrum method and FEMA 356 is used to evaluate the performance –based safety assessment of buildings. SAP 2000 vs. 14 is used to perform the pushover analysis of supporting buildings.

Safety assessment of pipelines is based on seismic design calculations developed by response displacement method in the critical urban infrastructure handbook. By checking SPT value from the collection of the soil bore hole test data, the soil profile types existing along the pipeline under study area are chosen based on the code, ATC-40.

Seismic Vulnerability Assessment is carried out by using the following procedures:

1) Firstly, the site soil data and supporting building information are collected.
2) The seismic hazard analysis for MOE, DBE and MCE is carried out for Thingangyun (Sanpya) hospital site. The peak ground acceleration at the bed rock is evaluated.
3) The bore hole test and microtremor test are carried out at the hospital campus. The soil amplification factors of surface soil strata for three earthquake levels are estimated by using the method developed by INOUE et al.
4) The peak ground accelerations at surface are evaluated.
5) Depending upon existing conditions, modeling of main hospital building, supporting structures, and water supply system in the campus and along lifeline are carried out.
6) For main hospital building and supporting structures, safety assessment to comply the required performance is performed by using pushover analysis. Safety assessment of pipelines is performed by using seismic design calculations developed by response displacement method.
7) Probability of failure of each component are evaluated and finally the vulnerability function of the whole system is developed.

A. *Seismic Hazard Analysis*

The seismic hazard analysis for three earthquake levels is determined by the probabilistic seismic hazard analysis (PSHA). The estimated seismic hazard levels are based on the seismic hazard assessment for Myanmar developed by Myanmar Earthquake Committee (MEC) and Myanmar Geosciences Society (MGS) and bounded Gutenberg-Richter recurrence law [3].

Only Sagaing fault is considered as a line source. The cumulative probability distribution function of moment magnitudes is estimated by

$$F_M(m_j) = \frac{1-10^{-b(M-M_{min})}}{1-10^{-b(M_{max}-M_{min})}} \tag{1}$$

where F_M (m_j) is cumulative probability distribution function; M is moment magnitude; b is constant.

Probability of occurrence of discrete set of magnitudes is determined by

$$P\left(M = m_j\right) = F_M(m_{j+1}) - F_M(m_j) \tag{2}$$

The annual rate of exceedance curve as a function of corresponding moment magnitudes for Sagaing fault is presented in **Figure 5**.

An earthquake level is defined with a probability of being exceeded in a specific period.

For MOE: 50% in 50 years
For DBE: 10% in 50 years
For MCE: 2% in 50 years

The return periods of three levels of earthquake can be calculated by

$$T = \frac{1}{1-(1-P)^{1/n}} \tag{3}$$

Then, the probability of occurrence in any year for each earthquake level can be calculated by $T = \frac{1}{P}$. After that the associated magnitudes for three earthquake levels are estimated using **Figure 5**.

After that the peak ground acceleration (PGA) at bed rock can be estimated using the following equation:

$$\ln PGA = -0.152 + 0.859M - 1.803\ln(R+25) \tag{4}$$

where, PGA is peak ground acceleration (g); M is moment magnitude; R is epicentral distance from the source (km). The calculated results are described in **Table 1**.

B. *Ground Motion Parameter s Evaluation*

Thingangyun (Sanpya) hospital is underlying the alluvial deposits. To investigate the soil conditions of the selected area, bore hole test and microtremor test are carried out. Based on the test results, the nonlinear soil amplification factor is evaluated.

Finally, the peak ground accelerations at ground surface for three earthquake levels are calculated by using:

$$G_s(T) = \frac{PGA_s}{PGA_b} \tag{5}$$

where, $G_s(T)$ is soil amplification factor of the site; $(PGA)_b$ is peak ground acceleration at bed rock; $(PGA)_s$ is peak ground acceleration at ground surface

From probabilistic seismic hazard analysis, the estimated moment magnitudes, peak ground acceleration at surface in which correspond to MOE, DBE and MCE are summarized in **Table 1**.

C. *Structural Safety Assessment*

The safety assessment of structures and water supply system is conducted in three parts as (i) safety assessment of main hospital building and supporting buildings, (ii) safety assessment of pipeline network and (iii) water lifeline system.

(1) Main hospital building and supporting buildings

(1.1)Building configurations

In main hospital building, A block is two-storeyed and B, C, D blocks are three-storeyed R.C building with brick walls (**Figure 4.**). The 3D modeling of the building is shown in **Figure 6**. For assessment, the building is divided into four sections as described in **Table 2**.

The supporting buildings for water supply system include underground water tank, pump house, elevated water tank and ground tank. The configurations of these structures are different in terms of height, existing conditions, locations, function, and their seismic resiliency. Pump house, elevated water tank and ground tank are above-ground structures whereas underground tank is under-ground structure. All the supporting structures are assumed to be reinforced concrete structures. Modeling of these structures are shown in **Figure 7** to **11**.

Material properties used are 3000 psi (20.684 MPa) for concrete strength (f'_c) and 50000 psi (344.738 MPa) for rebar strength (f_y).

(1.2) Safety assessment of buildings

From performance point of pushover analysis, the maximum inelastic displacement of the structures can be obtained to assess the safety to comply the performance requirements. The critical displacements of supporting framed buildings are considered as 1% of total height for IO under MOE, 2% of total height for LS under DBE, and 4% of total height for CP under MCE. The critical displacements of supporting wall structures are 0.5% of total height for IO, 1% of total height for LS, and 2% of total height for CP respectively based on FEMA 356 [7].

The probability of failure is evaluated by using the maximum inelastic displacement obtained from the pushover analysis and the critical displacement according to FEMA 356. It is calculated by the following equation:

$$\begin{aligned} P_f &= P\left[Z<0\,|EQ\right] \\ P_f &= P\left[\text{Capacity}^{EQ} < \text{Demand}^{EQ}\,|EQ\right] \\ P_f &= P\left[u_{cr}^{EQ} < u_{max}^{EQ}\,|EQ\right] \\ &= 1-\phi\left[\frac{u_{cr}-u_{max}}{\sqrt{\sigma_{cr}^2+\sigma_{max}^2}}\right] \end{aligned} \tag{6}$$

where, P_f is probability of failure; Z is demand – capacity; EQ is earthquakes; u_{cr}^{EQ} is critical displacement for a certain limit state; u_{max}^{EQ} is maximum displacement due to a certain earthquake; σ is standard deviation; μ is mean value and ϕ is standard normal distribution. The fragility curves of hospital building and its supporting structures are shown in **Figure 14** to **21**.

(2) Water supply system in hospital campus and lifeline system

(2.1) Pipeline configurations in hospital campus

The pipelines in the system are different in material used, depth, and length of segment. The types of materials are cast iron (CI) and polyvinyl chloride (PVC). The life span of CI and PVC can be assumed as 75 to 100 years so that the existing pipeline can be assumed as new-typed joints. But the design of these existing pipelines was not performed for seismic load case. Therefore it will take considerable to replace all of them for future earthquakes. Replacing all of these types of joint will require an enormous investment. Therefore, it is necessary to consider a partial and selective retrofitting scheme. Performance-based safety assessment of existing pipelines is necessary for the retrofitting scheme.

All the connection types between the two segments are mechanical joint and the failure mode of this type of joint is due to excessive joint axial displacement. Therefore, in this study, the safety assessment of water pipelines is carried out in terms of joint axial displacement. The existing conditions of pipelines and joints are shown in **Figure 12 (a)**.

(2.2) Water lifeline system along the study area

The study area is along the path from Water lifeline system along study area Ngamoeyeik reservoir to Nyaung Na Pin water treatment plant and then to Thingangyun (Sanpya) Hospital. The reservoir is constructed in 1995 and is kind of open channel. Another water source, Gyobyu reservoir, is linked to the pipeline for non-occurrence of water shortage due to emergency condition.

To reach out the water to target area, water lifeline pass through four townships: Mingalardon, North Oakkalarpa, South Oakkalarpa, and Thingangyun. Along the path, various types and diameter of pipes such as mild steel pipe (MS), pressurized concrete pipe (PCP), high density polyethylene pipes (HDPE), cast iron pipe (CI), and poly vinyl chloride pipe (PVC) are used. The connection types between the two pipes are used as both mechanical and continuous joints.

Schematic configuration and modelling of existing water supply pipeline are shown in **Figure 13**.

(2.3) Safety assessment of water pipelines

In the safety assessment of pipelines, the horizontally travelling seismic waves that are transmitted to the incident angle of 45 degree to the pipelines are considered as seismic load. The seismic performance of the pipes are assessed by seismic design guideline from Japan Water Work Association (JWWA).

In joint axial displacement calculation process, the soil properties, the material properties and detail measurement of pipes, and the seismic loads are taking into account. For seismic case, spectral velocity is used as a demand parameter in the calculation of ground response. This value for study area are shown in **Table 3**.

For knowing the probability of failure of each pipe, the fragility curves of each pipe segment (shown in **Figure 12(b)** and **Figure 13(b)**) are developed as a function of spectral acceleration. The fragility curves are developed using the displacements obtained from pushover analysis and joint axial displacement calculation for various spectral accelerations.

The probability of failure of a segment can be determined by:

$$P_f = 1 - \prod_{j=1}^{N} \left\{ 1 - P\left[\Delta_{cr}^{EQ} < \Delta_{max}^{EQ} \middle| EQ \right] \right\} \tag{7}$$

The developed fragility curves for water pipe lines are shown in **Figure 22** to **26.**

III. RESULTS AND DISCUSSION

In this study the vulnerability of a structure is expressed in terms of probability of failure. The vulnerability conditions are shown in **Table 4**. Based on these conditions, the following can be concluded:

For main hospital building-

1. Section 3 and 4 are more vulnerable than other sections.
2. The whole structure need to retrofit to withstand under DBE earthquake level.
3. But the building may not be resisted under MCE earthquake level.
4. The building should be retrofitted and rehabilitated.

For supporting structures-

1. The two underground tanks are not vulnerable to future earthquakes and has highest reliability than other supporting buildings.
2. The most vulnerable structure is elevated water tank.
3. Pump house and elevated water tank should be retrofitted to withstand under MOE, DBE and MCE earthquake levels.

For water supply system in the campus

1. It is found that mechanical joints are very vulnerable to earthquakes. So pipe joints are the weakest points in the system.
2. Almost all the pipe joints will fail their target performances with the probability of failure of greater than 80% under three earthquake levels. So retrofitting of pipe joints is required.
3. The water supply system in Thingangyun hospital is very vulnerable to earthquake since it is a series system.
4. For future earthquakes, the existing system should be retrofitted.

For water lifeline system along study area

1. All mechanical joint pipes have 100% probabilities of failure in three seismic levels whereas the continuous ones have no failure stages under MOE and DBE earthquake levels.
2. The probability of connectivity at each link for the whole network has a weak point because it will not be sure to get enough water if the pipelines are existing as far as away from the source.
3. This shows that the alert for aging pipes, especially mechanical joint pipes, should be replaced with newly developed pipes based on seismic design guideline.

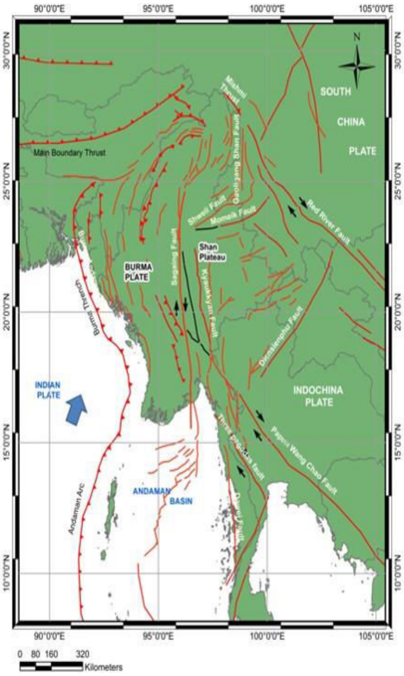


Figure 1. Myanmar map with active faults

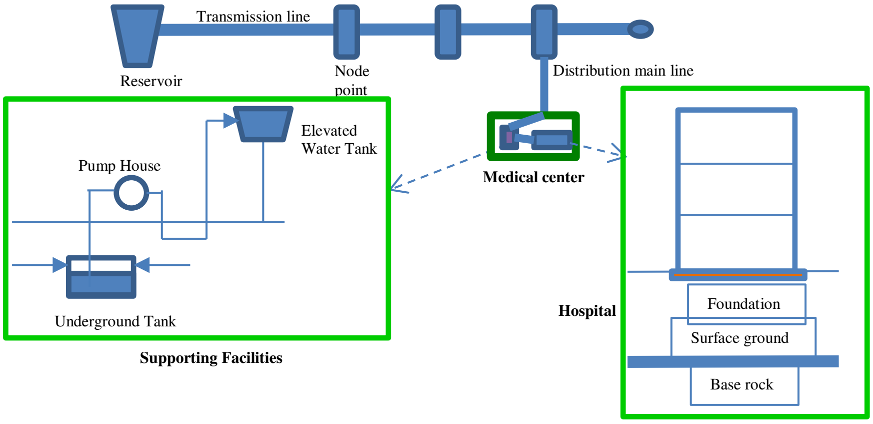
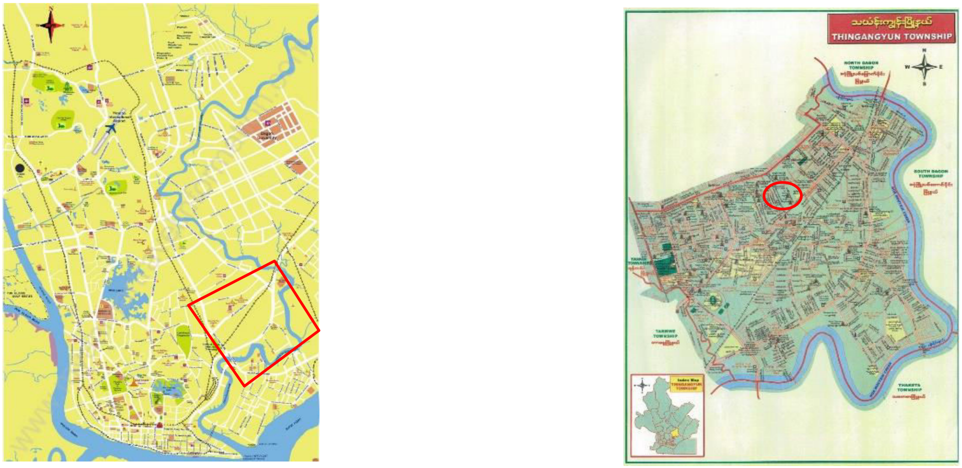


Figure 2. Schematic illustration of selected area of the study



(a) (b)

Figure 3. (a) Yangon map (Selected portion is Thingangyun township),
(b) Thingangyun township (Selected portion is location of the selected hospital)

Figure 4. Site plan of Thingangyun (Sanpya) hospital

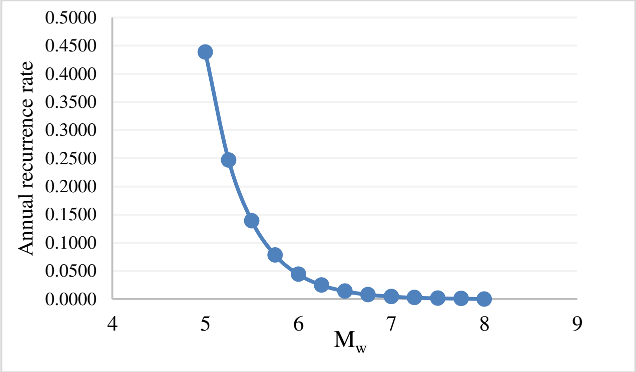


Figure 5. Illustrating the annual rate of exceedance of certain earthquake

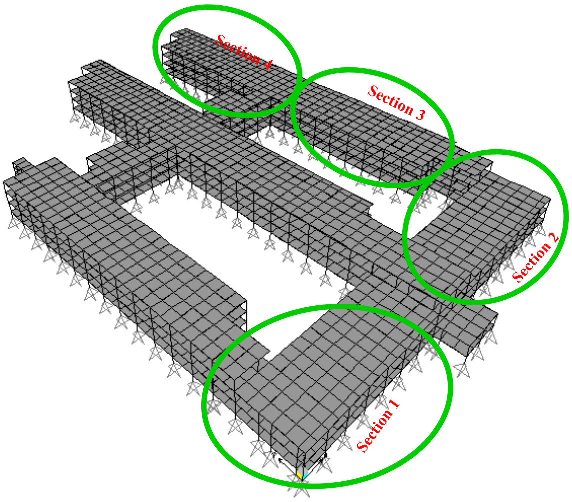
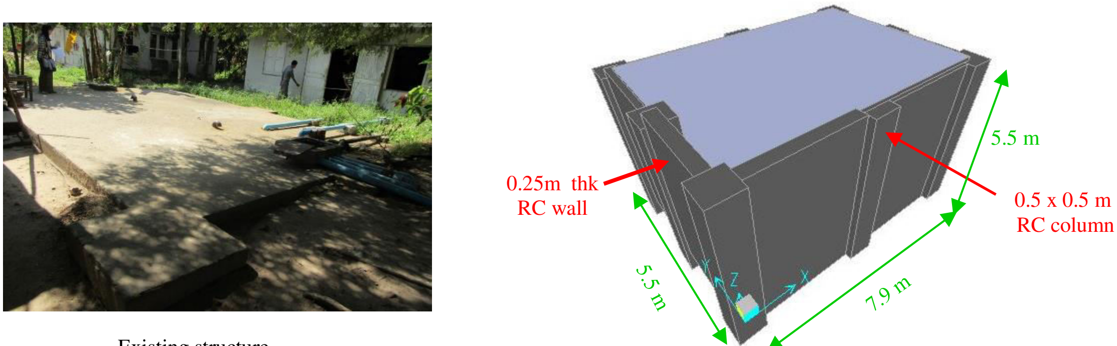


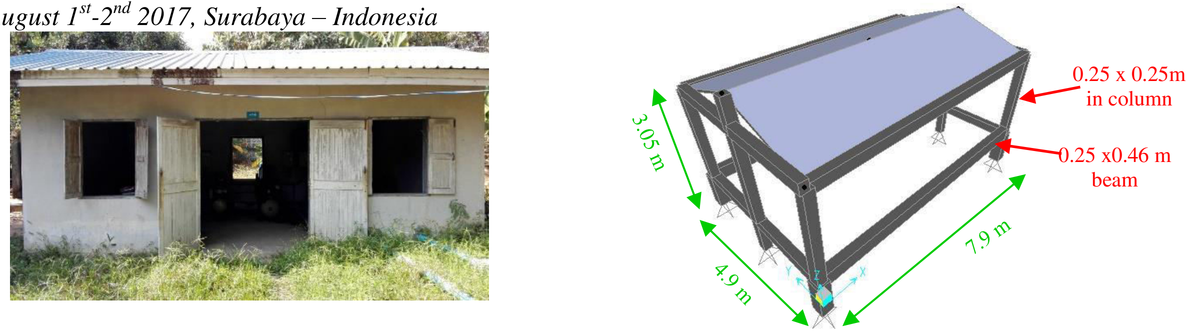
Figure 6. 3D View of Thingangyun Sanpya General Hospital



Existing structure

3D modeling of underground water tank

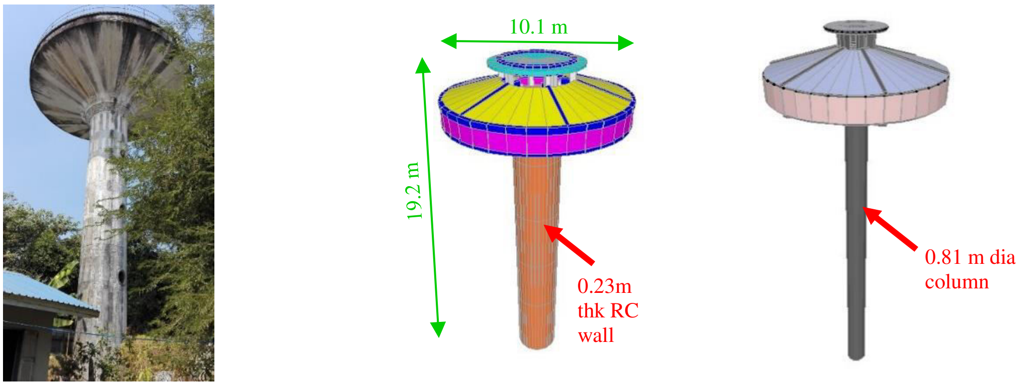
Figure 7. Modeling of underground water tank 1



Existing structure

3D modeling of pump house

Figure 8. Modeling of pump house

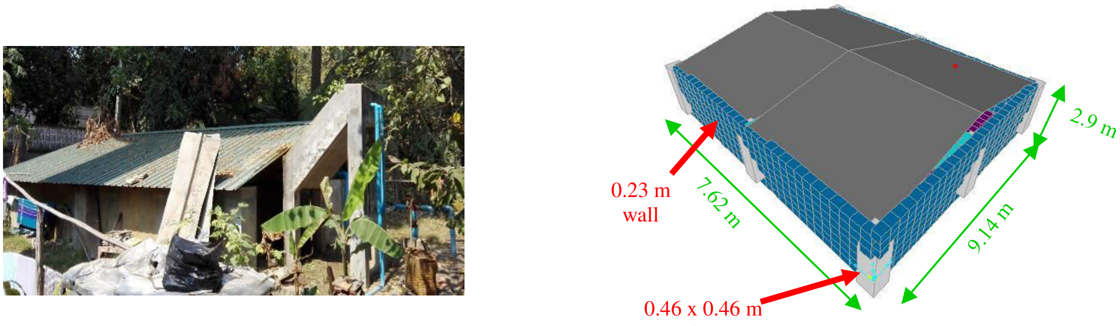


Existing structure

3D modeling of elevated water tank

Equivalent frame modeling of elevated water tank

Figure 9. Modeling of elevated water tank

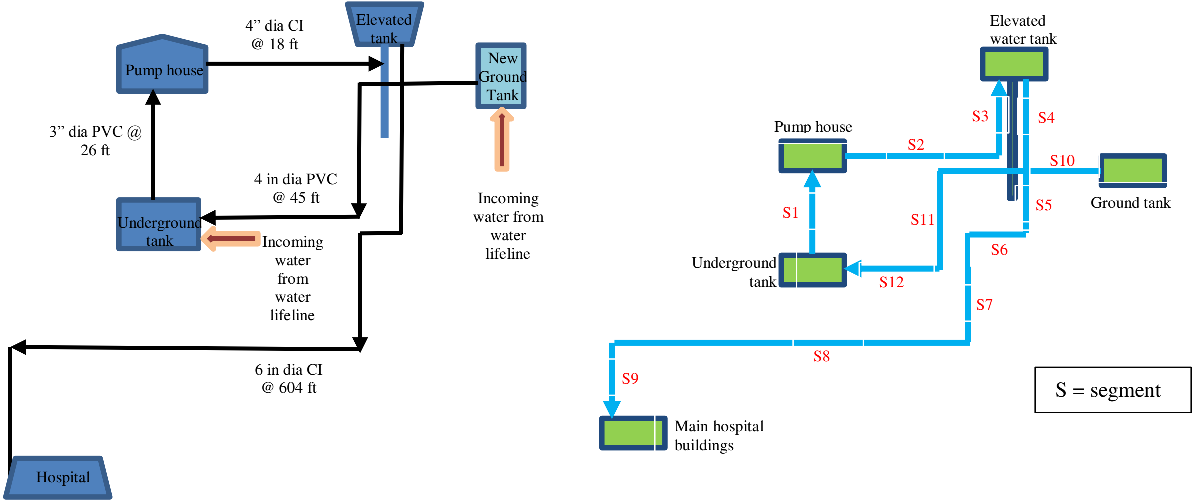


Existing structure

3D modeling of underground tank

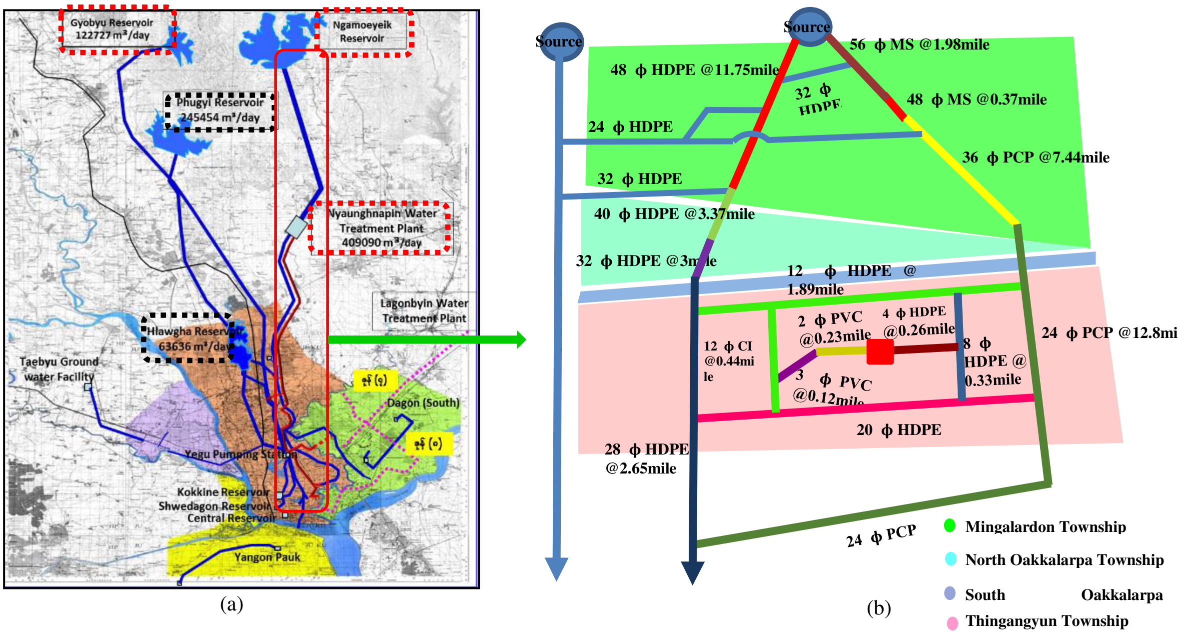
Figure 10. Modeling of underground water tank 2

Figure 11. Existing Conditions of Some Pipe Segments and Pipe Joints



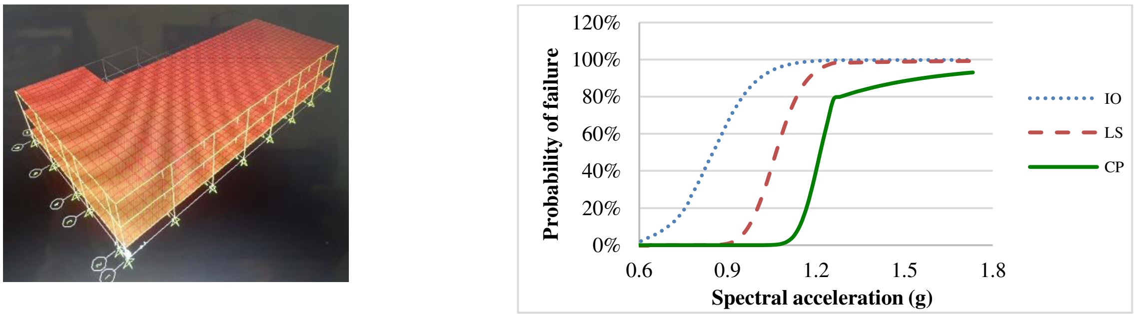
(a) (b)

Figure 12. (a) Plan configuration of water supply system in the hospital; (b) Modelling of water supply system in the hospital



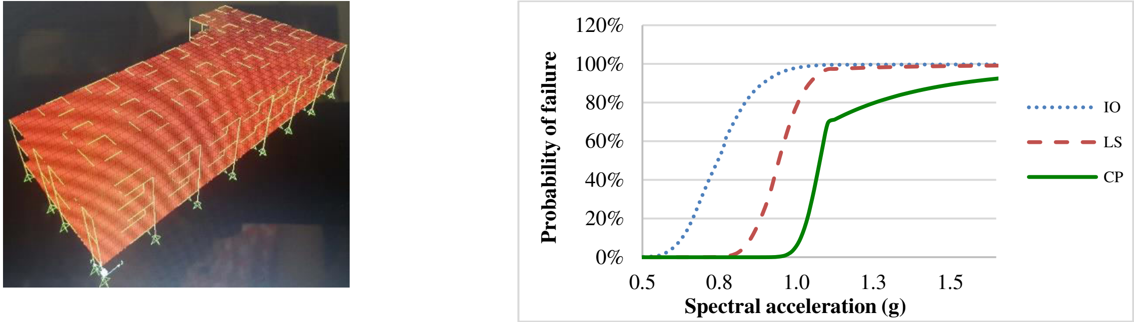
(a) (b)

Figure 13. (a) Schematic configuration of existing water system of Yangon,
(b) Modelling of existing water supply system from Nyaung Hna Pin water treatment plant to Sanpya Hospital



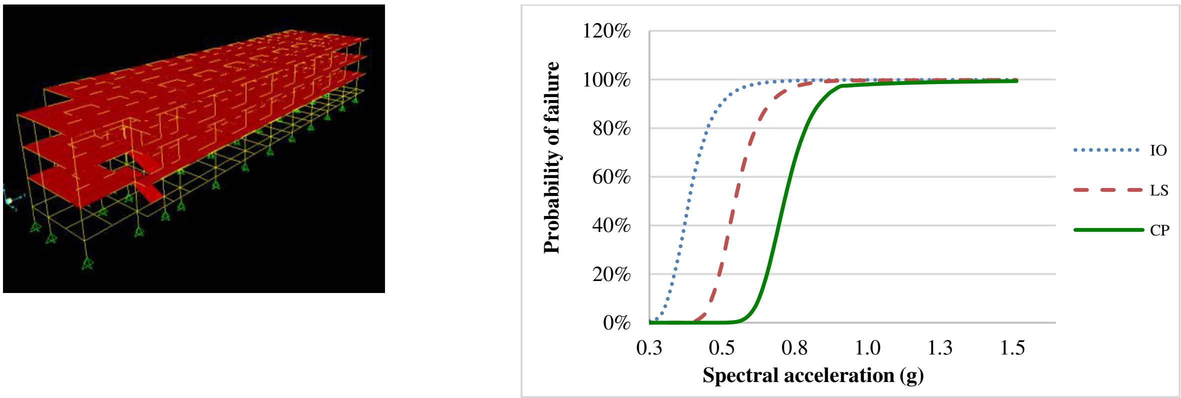
(a) (b)

Figure 14. (a) Section 1 of main hospital building; (b) Fragility curves of section 1 for MOE, DBE and MCE levels



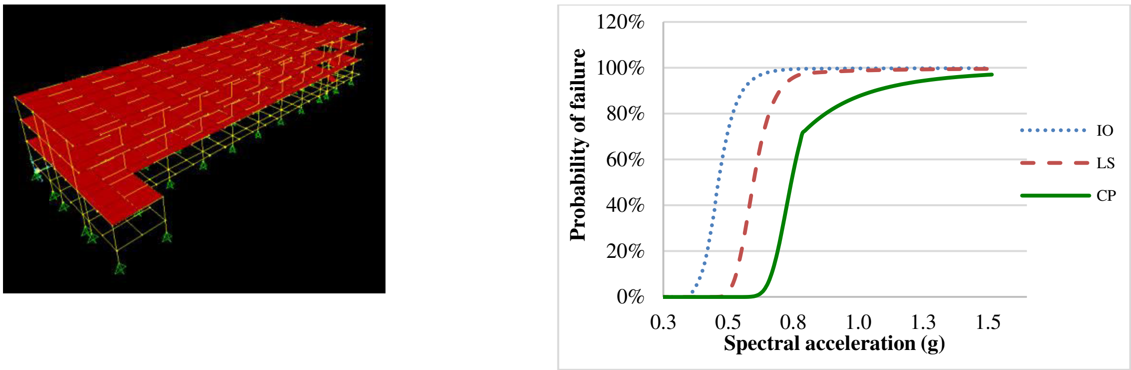
(a) (b)

Figure 15. (a) Section 2 of main hospital building; (b) Fragility curves of section 2 for MOE, DBE and MCE levels



(a) (b)

Figure 16. (a) Section 3 of main hospital building; (b) Fragility curves of section 3 for MOE, DBE and MCE levels



(a) (b)

Figure 17. (a) Section 4 of main hospital building; (b) Fragility curves of section 4 for MOE, DBE and MCE levels

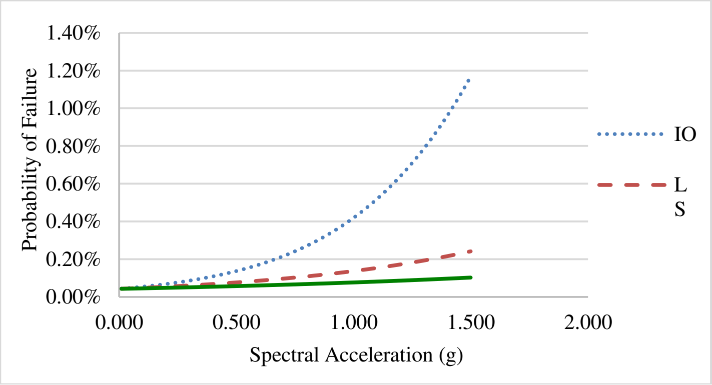


Figure 18. Fragility curves of underground water tank 1

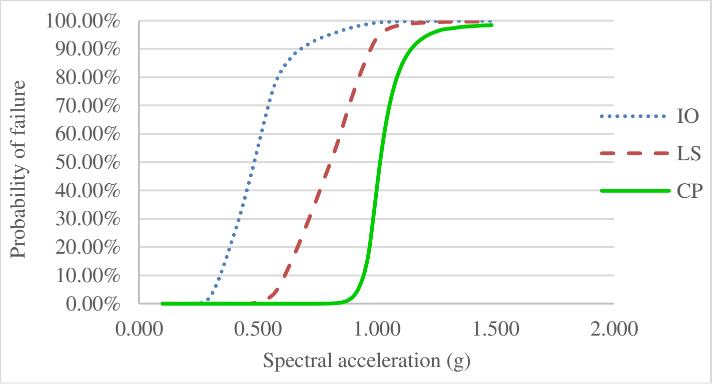


Figure 19. Fragility curves of pump house

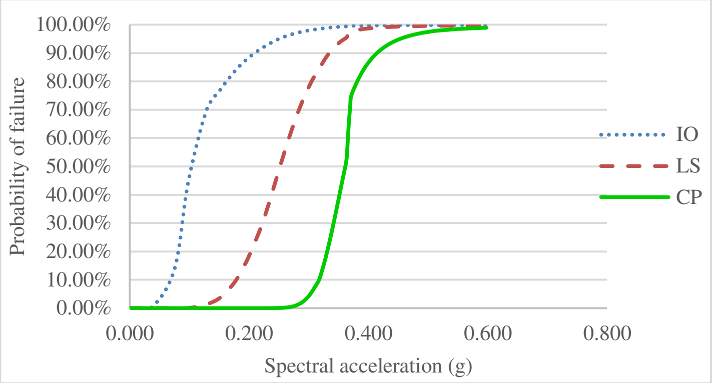


Figure 20. Fragility curves of elevated water tank

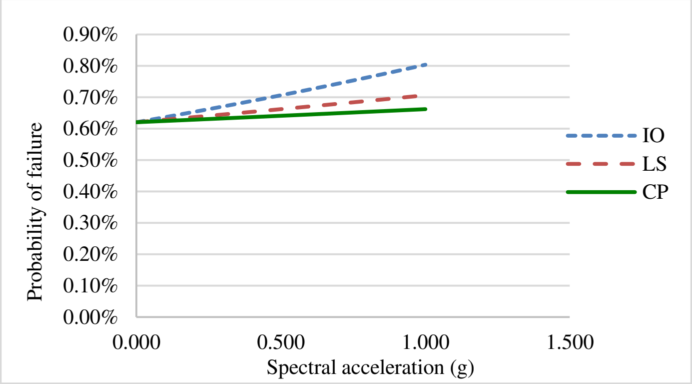


Figure 21. Fragility curves of underground water tank 2

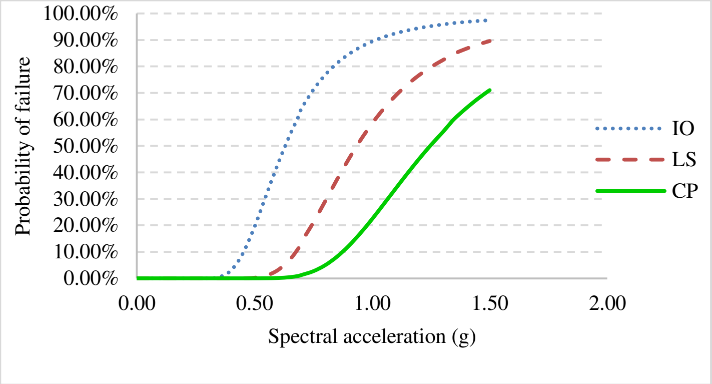


Figure 22. Fragility curves of pipe segment 1(PVC pipe) from internal water supply system

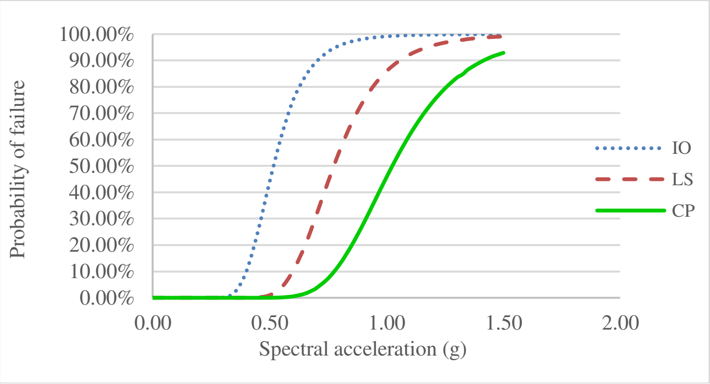


Figure 23. Fragility curves of pipe segment 3(CI pipe) from internal water supply system

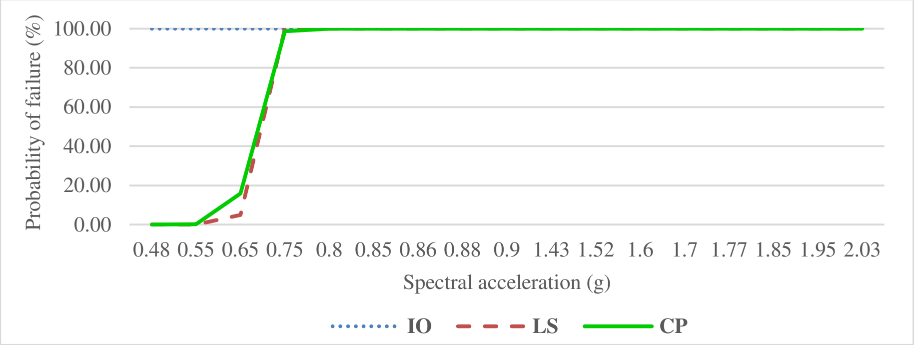


Figure 24. Fragility curves of 24" diameter PCP pipe at Thingangyun Township

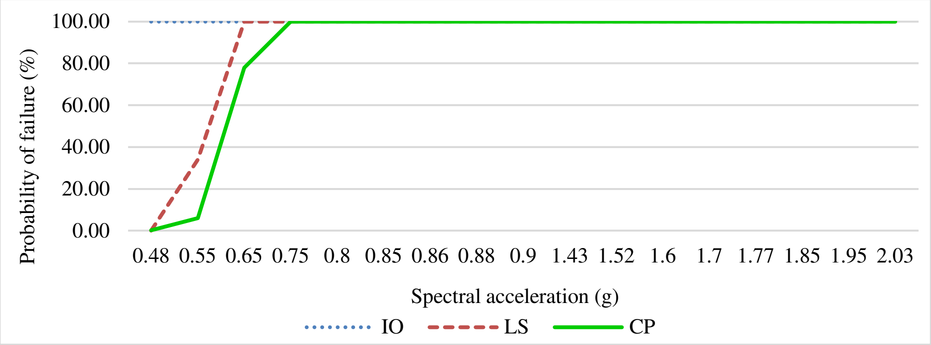


Figure 25. Fragility curves of 12" diameter CI pipe at Thingangyun Township

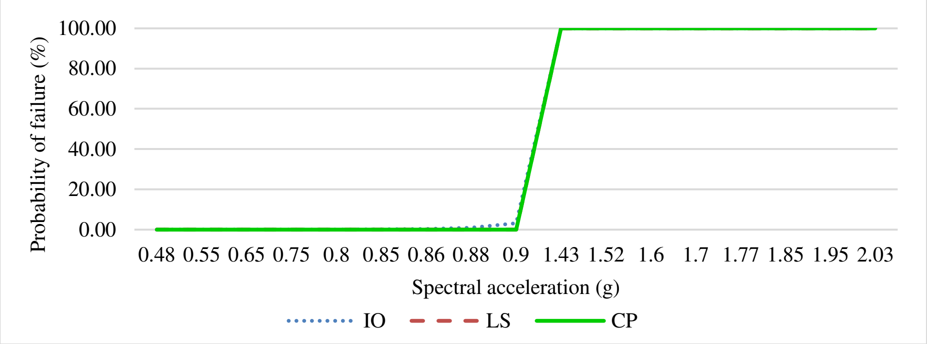


Figure 26. Fragility curves of 12" diameter HDPE pipe at Thingangyun Township

Table 1. Seismic hazard analysis results

Earthquakes	Probability of exceedence in 50 years	Return Period (years)	Moment Magnitude M_w	$(PGA)_b$ (g)	G_s	$(PGA)_s$ (g)
MOE	50%	73	6.51	0.0959	1.62	0.1554
DBE	10%	275	7.34	0.1957	1.66	0.3249
MCE	2%	2475	7.87	0.3085	1.91	0.5892

Table 2. Dimensions of buildings for case studies

Section	L(ft.)	B(ft.)	H(ft.)	L/B	No. of Stories
1	140	75	22	1.86	2
2	140	75	22	1.86	2
3	200	55	33	3.64	3
4	200	55	33	3.64	3

Table 3. Spectral velocities of MOE, DBE and MCE levels for four townships

	RESPONSE VELOCITY SPECTRUM (S_v) m/s			
EARTHQUAKE	Mingalardon	North Oakkalarpa	South Oakkalarpa	Thingangyun
MOE	0.366	0.366	0.366	0.361
DBE	0.426	0.426	0.426	0.42
MCE	1.090	1.090	1.090	1.075

Table 4. Probability of Failure (Vulnerable conditions) of Each Structure

Structures	Earthquake Levels	Target Performance Levels		P_f (%)
		Performances	Damage States	
Main Building: Section 1	MOE	IO	Minor wall cracks <1/16in	21.03
	DBE	LS	Crushing & flexural cracking	0.83
	MCE	CP	Serve boundary element damage	91.77
Main Building: Section 2	MOE	IO	Minor wall cracks <1/16in	55.6
	DBE	LS	Crushing & flexural cracking	26.36
	MCE	CP	Serve boundary element damage	92.4
Main Building: Section 3	MOE	IO	Minor wall cracks <1/16in	77.24
	DBE	LS	Crushing & flexural cracking	96.97
	MCE	CP	Serve boundary element damage	99.36
Main Building: Section 4	MOE	IO	Minor wall cracks <1/16in	35.77
	DBE	LS	Crushing & flexural cracking	95.65
	MCE	CP	Serve boundary element damage	97.07
Under-ground water tank	MOE	IO	Minor wall cracks <1/16in	0.17
	DBE	LS	Crushing & flexural cracking	0.09
	MCE	CP	Serve boundary element damage	0.07
Pump House	MOE	IO	Hairline cracks & limited yielding	93.6
	DBE	LS	Beam damage, column shear cracks	73.8
	MCE	CP	Hinge formations, splice failure	97.3
Elevated water tank	MOE	IO	Minor wall cracks <1/16in	87.4
	DBE	LS	Crushing & flexural cracking	88.2
	MCE	CP	Serve boundary element damage	98.2
Ground water tank	MOE	IO	Minor wall cracks <1/16in	0.69
	DBE	LS	Crushing & flexural cracking	0.64
	MCE	CP	Serve boundary element damage	0.65
Water supply system in the campus	MOE	IO	Small leakage of water from joint	35 to 100
	DBE	LS	Large leakage of water from joint	14 to 100
	MCE	CP	The joint is pull-out	34 to 100
Water lifeline	MOE	IO	Small leakage of water from joint	100

system	DBE	LS	Large leakage of water from joint	100
	MCE	CP	The joint is pull-out	100

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