INVESTIGATION OF SEISMIC DAMAGE TO HIGH-RISE BUILDINGS IN BANGKOK CAUSED BY THE MYANMAR EARTHQUAKE AND EXPERIMENT PLAN ON ROOFTOP POOL SLOSHING AND OVERFLOW

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1. INTRODUCTION

In March 2025, Mandalay earthquake occurred in central Myanmar, many high-rise buildings in the Bangkok metropolitan area of Thailand, located more than 1,000km away from the epicenter, swayed significantly, and some buildings were damaged. For example, equipment installed on building rooftops overturned, connecting bridge between multiple buildings were damaged, and glass fences fell out due to overflowing water from rooftop pools. These earthquake damages are thought to be caused by long-period seismic motions amplified in the deep ground, which affected the large seismic response of high-rise buildings in the Bangkok metropolitan area.

In this study, we investigated the damage to 19 high-rise buildings in Bangkok, Thailand, and summarized the earthquake damage mainly to non-structural components. Furthermore, based on the fact that damage caused by overflowing water from rooftop pools was observed in many high-rise buildings, we planned the water sloshing experiment using a shaking table device.

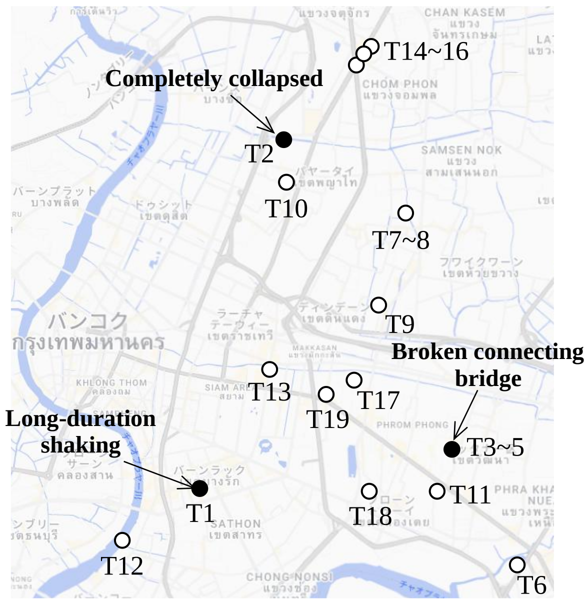


Figure 1. Locations of the 19 buildings in this investigation

2. RESULTS OF INVESTIGATION

The locations of the 19 buildings surveyed are shown in Figure 1. In the figure, buildings where damage caused by overflowing water from rooftop pools was confirmed are indicated by white dots, while the others are indicated by black ones. Building T2 was completely collapsed under construction, buildings T3~5 was damaged to the connecting bridge between each other building during the earthquake, and video recordings of both buildings taken by local residents remain. This chapter describes the damage to non-structural components and rooftop pools in buildings T9 and T19.

(a) Peeling of exterior wall (b) Roof surface

Figure 2. Damage at the outer perimeter

(a) Broken fence (b) Over turning of units

Figure 3. Damage on the rooftop floor

Firstly, the condition of non-structural components is described. Figure 2 shows the main damage observed at the outer perimeter. In the investigation of the buildings' exterior, peeling and cracking of the exterior walls (Figure 2 (a)), and damage to the roof surface that appeared to be caused by falling some objects from the rooftop (Figure 2 (b)) were observed. Figure 3 shows the main damage observed on the rooftop floor. In the investigation of the rooftop floor of the building, damage to the fence (Figure 3 (a)) and over turning of outdoor units (Figure 3 (b)) were observed. From these damages, it is thought that the seismic response on the rooftop floor of the high-rise building was quite significant due to long-period seismic motion.

Next, the condition of the rooftop pool is described. Figure 4 shows the damage observed at the rooftop pool. In this building's rooftop pool, it is easy to conclude that the pool water shook violently during the earthquake, causing the fence to fall (Figure 4 (a)). In addition, it was observed that the anchor bolts that were likely to be secured the fence were damaged at the fence installation site (Figure 4 (b)). Furthermore, in the investigation, the dimension of the rooftop pool and the depth of the remaining water were measured by using a laser displacement transducer to estimate how much water overflowed during the earthquake.

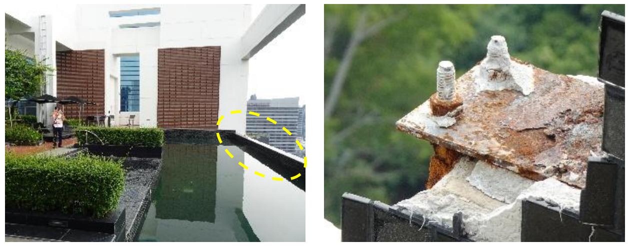
3. WATER SLOSHING EXPERIMENT SIMULATING ROOFTOP POOL

Based on the results of the investigation, we will describe the plan for a water sloshing experiment simulating a rooftop pool in high-rise building. Before designing the test specimen, it is necessary to determine the dimensions of the pool to be used as the test specimen based on the theory of sloshing [1]. In this experiment, the pool is treated as a two-dimensional tank, and water is assumed to be incompressible, non-viscous, irrotational, and linear when applying fluid equations. The sloshing of water can be decomposed into quasi-static and dynamic components. In this study, the quasi-static component represents the slope of the water surface when gravity and inertial forces act statically on the water. The dynamic component can be represented as primary mode, secondary mode, etc. (Figure 5). We let η_i (i=0,1,2, …) be the sloshing height of water in each mode. Then, the sloshing height of water in the pool is a superposition of each mode and is expressed by the following equation.

$$\eta = \sum_{i=0}^{n} \eta_i \tag{1}$$

The colored areas in Figure 5 represents the overflow volume of water in each mode. This is calculated by integrating this area in each mode, and by superimposing them, the predicted overflow volume V of the pool is calculated and expressed by the following equation.

$$V = \left| \int_0^{L/2} \left(\eta_0 \cdot \frac{x}{L/2} + \sum_{i=1}^{n} \eta_i \cdot (-1)^{i-1} \cdot \sin \frac{(2i-1)\pi x}{L} \right) dx \right| \tag{2}$$



(a) Fallen fences (b) Bolts that secured fences

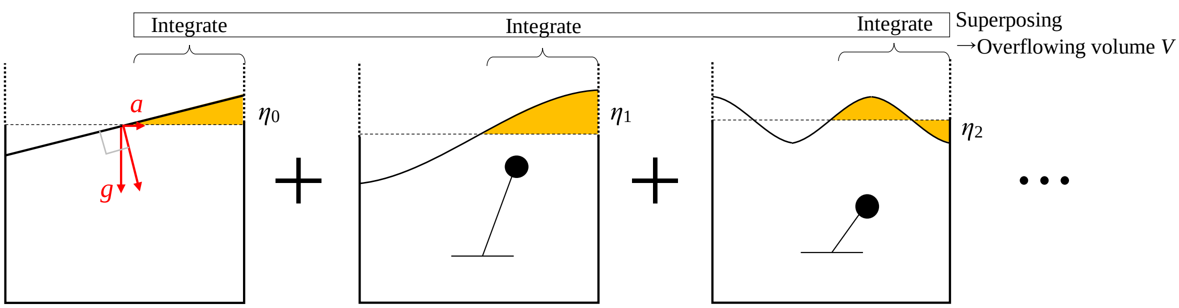
Figure 4. Damage at the rooftop pool

Here, L is the width of the pool, and the x-coordinate is set to $-L/2 \leqq x \leqq L/2$, with the center of the pool width as the origin. However, when the shaking table and the water in the pool vibrate sympathetically, the primary mode is dominant, so the natural period can be approximated as being almost the same as first natural period. The first natural period T of a pool with a water depth H is expressed by the following equation.

$$T = 2\pi \sqrt{\frac{L}{\pi g} \cdot \coth \frac{L}{\pi H}} \tag{3}$$

Equation (3) shows that the pool width L and aspect ratio H/L are closely related to the natural period of the pool. Based on Equation (3), the relationship between the aspect ratio H/L and the first natural period T is shown in Figure 6. As shown in the figure, the smaller the aspect ratio, the longer the natural period. In other words, when water overflows and the water level drops during vibration, the natural period of the pool may become even longer.

Based on the above theory, we will discuss the planned test specimen. Because of equipment limitations, this experiment will be conducted using scaled-down test specimens instead of a full-size pool. The test parameters are the pool width L, the aspect ratio H/L, and the ratio of the excitation period to the natural period of the pool, T_p/T. The above is summarized in Table1, which lists the test specimens used in this experiment. The test specimens are classified into four series, combing two types of widths (L=500 and 1,000mm), and two types of aspect ratios (H/L=0.50 and 1.0). Furthermore, three types of T_p/T=1.2, 1.5, and 2.0 are prepared for each series, and the input amplitude required to reach η=10cm is set in the calculation. In this study, the pool is considered to be a two-dimensional tank, and the walls are set high to prevent water overflow from the vibration orthogonal direction.



(a) Quasi-static component (b) Primary component (c) Secondary component

Figure 5. Sloshing height of water and overflowing volume during horizontal vibration

The test setup is shown in Figure 7. The experimental device consists of loading frame, shaking table, actuator, and a test specimen that simulates a pool. The loading frame is supported by two columns connected to the upper and lower sides of the reaction frame with pins, allowing it to move freely in the horizontal direction. Since the pin loading section is connected to the middle of the columns, under ideal geometric linear conditions, the displacement applied by actuator is amplified 42 times and applied to the test specimen. The test specimen is placed on the shaking table, and a steel jig simulating a fence is installed about 100mm away from the test specimen.

The measurement plan is shown in Figure 8. The measurement items are the overflow volume of water and the pressure exerted on the fence when water overflows. First, we will describe the method for measuring the overflow volume of water. Acrylic cylinders are attached to the walls of the pool tank, and a floating ball is placed inside the cylinders. The ends of the cylinder are open, and the internal water pressure is adjusted to match atmospheric pressure. The water level change is measured by placing laser displacement transducer from the shaking table, and overflow volume of water can be calculated. (Figure 8 (a)). Next, we will describe the method for measuring the pressure exerted on the fence. The fence is constructed using L-shaped steel jig, with four load cells installed vertically between the fence and the shaking table. Two load cells installed horizontally on the fence wall, and the horizontal reaction force is measured by sandwiching them between the fence and the jig installed from the shaking table. The horizontal load cells measure the pressure acting on the fence. In addition, the moment at the bottom of the fence is calculated based on the values measured by the four loadcells installed vertically, and the height at which the horizontal force acts on the fence is determined by dividing that by the measured horizontal force. (Figure 8 (b)).

Finally, the loading method will be described. In this experiment, the side where the actuator is pulled is defined as positive, and sinusoidal waveform is applied with constant displacement amplitude alternating between positive and negative. Loading continues until there is no longer any observable overflow from the pool.

Table 1. Specimen list

Case	Width L [mm]	Aspect ratio H/L	Natural period T [s]	Excitation period T_p [s]	T_p/T	Displacement [mm]	Acceleration [cm/s^2]
Series 1	500	1.0	0.802	0.963	1.2	38	161
				1.20	1.5	116	317
				1.60	2.0	238	365
Series 2		0.50	0.836	1.00	1.2	41	161
				1.25	1.5	126	317
				1.67	2.0	259	365
Series 3	1,000	0.50	1.18	1.42	1.2	41	81
				1.77	1.5	126	158
				2.36	2.0	259	183
Series 4		1.0	1.40	1.68	1.2	58	81
				2.10	1.5	176	158
				2.80	2.0	363	183

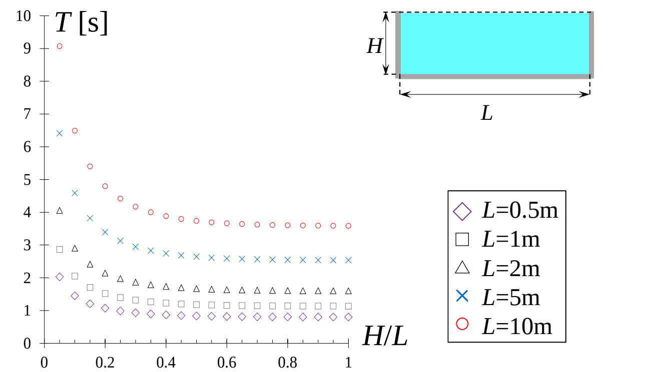


Figure 6. Relationship between pool size and natural period

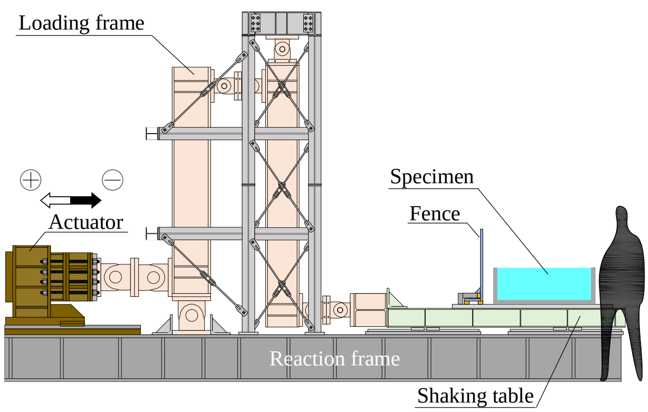
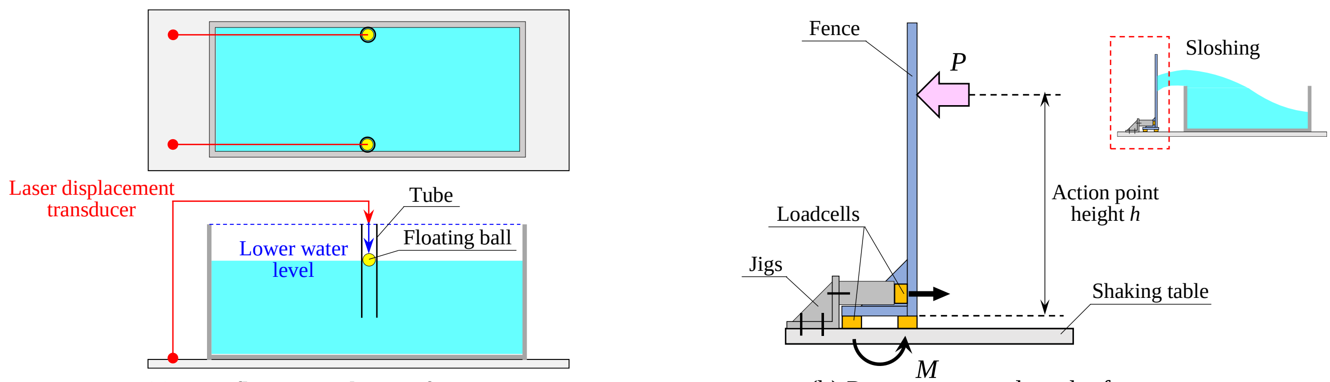


Figure 7. Test setup



(a) Overflowing volume of water

(b) Pressure exerted on the fence

Figure 8. Measurement plan

4. CONCLUSION

In this study, we investigated the damage to 19 high-rise buildings in Bangkok and summarized the earthquake damage mainly to non-structural components. Based on these facts, we planned an experiment about rooftop pool sloshing and overflowing. The results are as follows.

1) Some localized damage in high-rise buildings was observed in Bangkok, even more than 1,000km from epicenter. However, many buildings are still in usable condition.
2) In many high-rise buildings, water sloshing and overflowing of rooftop pools due to long-period, long-duration seismic motion was observed, resulting in damage to non-structural components and equipment.
3) Based on the theory of sloshing, we showed the plan of the water sloshing experiment using a scaled model of rooftop pool and the shaking table device. This experiment is scheduled to be conducted this autumn, and we'll conduct this research combining experimentation and numerical analysis in the future.

5. REFERENCES

[1] Keiji Komatsu: Sloshing, Liquid Surface Oscillation and Tank Vibration, Morikita Publishing, 2015