Shaking Table Test on Different Positions of Multiple Tuned Liquid Damper

Izzul Syazwan Ishak, Norliyati Mohd Amin, Norhayati Abdul Hamid

Abstract*: Earthquake can cause many problems to the structures, which lead to buildings collapse and may takes humans life. It is a nature's hazard that cannot be stop. One of the effort is by introducing the damping system to the buildings where the energy of the system is slowly reduced until the vibration of the system is totally eliminated and the system is brought to rest. Several techniques are available nowadays, however passive control system has advantage in term of cost compare to other systems. Multiple Tuned Liquid Damper (MTLD) is a passive system that traditionally made of several rigid tanks filled with water, usually placed on top of a building. The energy will dissipates through the sloshing and wave-breaking of the liquid once the earthquake strike the buildings. Shaking table tests are carried out on a two-bay, two-story steel frame with water tanks for different location. In this test, the displacement and acceleration for top and base are studied.

***Keywords* : Earthquake, multiple tuned liquid damper, shaking table, water tank.**

I. INTRODUCTION

Natural disasters fear the humankind since the day first. One of the nature hazard that caused major loss of life and severe damage to property, especially to man-made structures is earthquake. This problem occur when sudden energy release inside the earth due to the movement and breaking of tectonic plate. Landslide, ground settling, rock falls, liquefaction and tsunami are the products of earthquake that can affected the manmade structures as well as human life. Designing and constructing the strong structural element, sufficient enough to resist the earthquake force is one of the conventional method to mitigate the earthquake hazard. However, this method is very costly for developing countries, where the investments and budgets are great concern.

End of year 2002 and in the early 2003, two large earthquakes originated in Sumatra occurred with magnitude 7.4 and 5.8 respectively had caused panic to lot of people in several cities in Peninsular Malaysia but no damage or casualties were reported [1]. However, earthquake occurred on 2 November 2002 caused cracks on few buildings in Penang. One of the repairing technique was studied by Hamid [2] where the damage structural components was wrapped with carbon fiber reinforced polymer (CFRP). Malaysia is located in the stable Sunda Shelf with low to moderate seismic activity level that is why most of the building in Malaysia was not design to cater the earthquake however the earthquake activity nearby can felt in certain region in Malaysia. On 5 June 2015, a huge earthquake with magnitude 6.0 struck Ranau Sabah was the strongest in Malaysia since 1976, so it is better to upgrade the existing structure to withstand earthquake as precaution for the future. The ground movement cause the structure in motion, it is depends on applied load or displacement, mass, stiffness and damping [3].

Most of the tall buildings have water storage at the top of it as water supply, other than that it just add dead burden on the buildings, however it can be utilize as a damper to take over the energy transfer from the foundation to the structure [4]. Water tank is commonly a rigid tank filled with shallow water (h/L<0.15) where 'h' is water depth, 'L' is length of tank in the direction of motion [5]. It can be used as passive Tuned Liquid Damper (TLD) without affecting its functional use and at the same time embrace low cost and maintenance. When earthquake strike the TLD works based on liquid sloshing to absorb a portion of the dynamic energy and therefore controlling the structural vibration [5]. Large amount of sloshing and wave breaking occurs at the free surface of the liquid that dissipates a significant amount of energy when resonance occur where the frequency of tank motion is close to the frequency of the tank liquid.

Wakahara et al. [6] presented the capability of Multiple Tuned Liquid Damper (MTLD) by installed in real structures, Shin Yokohama Prince (SYP) hotel to reduce the structural vibration. Several investigations have shown that a single passive damper is not effective in reducing seismic responses [7]. First reason is the earthquake loads are typically impulsive and reach the maximum values promptly. A passive damper, subjected to a dynamic load typically is not set into significant motion in such a short period. Second, earthquake ground motions include a wide spectrum of frequency components and often induce significant vibration in both the natural and higher modes of a tall building structure. A single damper tuned to the structure natural frequency is unable to suppress the vibration of higher modes.

Single water tank as TLD will be placed at the center of the building so that each center of mass will coincide [8]. When a single TLD tank is engaged, its optimal frequency is tuned slightly less than the structural frequency. To broadens the frequency response curves, multiple tanks are used known as multiple tuned liquid damper (MTLD), where tanks sloshing frequencies are distributed over

Revised Manuscript Received on 20 October, 2019.

***** Correspondence Author

Izzul Syazwan Ishak*, Department of Civil Engineering, Universiti Teknologi Mara (UiTM) Shah Alam, Selangor, MALAYSIA. Email: izzul.syazwan@gmail.com

Norliyati Mohd Amin, Department of Civil Engineering, Universiti Teknologi Mara (UiTM) Shah Alam, Selangor, MALAYSIA. Email: norli830@uitm.edu.my

Norhayati Abdul Hamid, Institute for Infrastructure Engineering and Sustainable Management, Universiti Teknologi Mara (UiTM) Shah Alam, Selangor, MALAYSIA. Email: norha454@uitm.edu.my

a range near the structural frequency slightly above and below to get the greatest performance [9]. Each tank behaves uniquely, with each tank having its own natural frequency. Single TLD is mostly difficult to match with natural frequency of structure because of water sloshing behavior so MTLD is preferred because it is more effective for controlling frequency where it responds to changes in natural frequency of structures more easily [10].

The objective of this shaking table test is to study whether various arrangements of the MTLD has significant effect on structure response reduction.

II. EXPERIMENTAL SETUP

The dimension of steel model and arrangement of the steel-structure model over the shake table along with the MTLD model are shown in Fig. 1 and Fig. 2, respectively.

A. Shaking Table

The shaking table test was conducted at advanced civil laboratory at Universiti Tunku Abdul Rahman (UTAR) Sungai Long Campus, Selangor, Malaysia. The shaking table has dimension of 2m by 2m and electrically driven by direct drive motor (torque motor). Vertical load that can be applied depends on the supplied air pressure. Normally, when air pressure of 1 to 2 bar (i.e. 100KPa to 200KPa) vertical load of 2 to 4 tonnes can be placed on shaking table. For the horizontal shaking, performance of shaking table system is directly related to the combination effect of displacement and frequency. With slow shaking frequency, greater magnitude of displacement can be applied and vice versa. This shaking table allows two type of motions (1) Simple Cyclic Motion and (2) Random Wave Signal. In this research, Simple Cyclic Motion was selected. **Table- I** shows the input of shaking table used.

Table- I : Shaking table input data used for analysis

Level	Displacement, aggressiveness	Frequency, displacement	Acceleration average (m/s^2)
1	Large displacement, very low aggressiveness	F= 1 D= 3.0	Max= 8 Min= -8
2	Large displacement, low aggressiveness	F= 2 D= 3.0	Max= 14 Min= -15
3	Moderate displacement, low aggressiveness	F= 3 D= 1.5	Max= 14 Min= -14
4	Moderate displacement, low aggressiveness	F= 3 D= 1.9	Max= 15 Min= -15
5	Moderate displacement, aggressiveness	F= 5 D= 1.0	Max= 16 Min= -16
6	Short displacement, aggressive	F= 7 D= 0.7	Max= 15 Min= -16
7	Short displacement, aggressive	F= 8 D= 0.6	Max= 16 Min= -16
8	Short displacement, aggressive	F= 10 D= 0.6	Max= 17 Min= -16
	Short displacement, very aggressive	F= 15 D= 0.3	Max= 18 Min= -18
10	Short displacement, very aggressive	F= 15 D= 0.5	Max= 22 Min= -22

B. Steel Frame Structure

The test setup consists of two-bay, two-storey mild steel square hollow section as a beam with two plywood slabs attached to four mild steels square hollow section columns at an interval of 30 cm height. The steel size was 2.5 cm x 2.5 cm and the thickness of plywood slab was 1 cm. The entire structure weight was approximately 12 kg and attached on the shaking table. **Fig. 1** shows the dimension of the steel structure model and **Fig. 2** shows the full setup of MTLD-structure fitted on the shaking table base plate. Three accelerometers were used to record the data, placed at the base, middle and top of the structure as shown in **Fig. 3**.

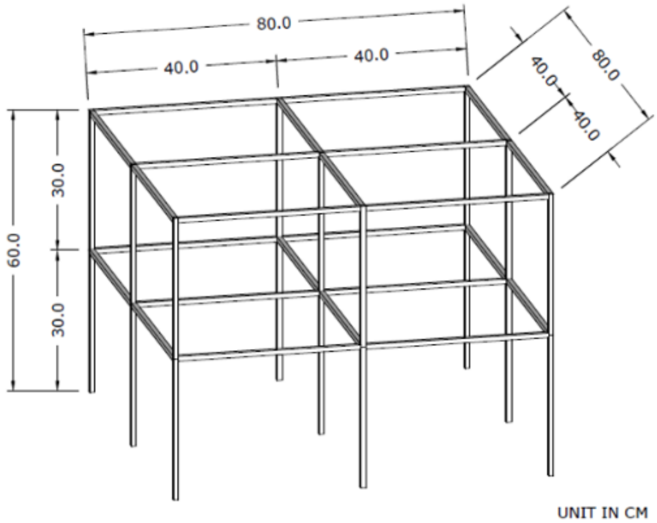

Fig. 1. Dimension of steel structure model

Fig. 2. MTLD-Structure fitted on shaking table

Fig. 3. Accelerometer located at the base, middle and top

C. Water tanks (Multiple Tuned Liquid Damper)

Four square water tanks were considered in the test. These water tanks will acting as a passive damper known as Multiple Tuned Liquid Damper

(MTLD). The MTLD models were made up of glass sheet of 3 mm thickness. The dimension of the water tanks were 30 cm x 30 cm x30 cm with approximate weight of 2.4 kg. All tanks were filled with ¾ liquid. The liquid used for all MTLD was water with a density of 1000kg/m^3 and bulk modulus of 2.15 GPa.

D. MTLD Positions

There were 4 arrangement of MTLD position considered in the test. **Fig. 4** shows the details of the arrangement:

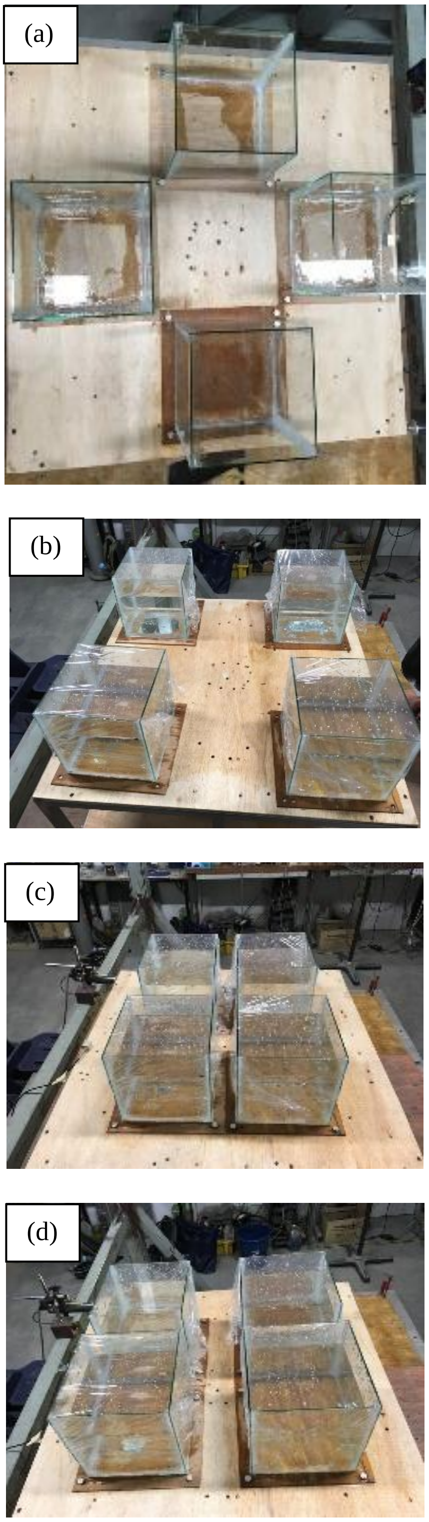

Fig. 4. MTLD position-Arrangement (a) 1 (b) 2 (c) 3 and (d) 4

III. RESULTS AND DISCUSSION

The objective of this MTLD shaking table test is to find and study whether the various position of MTLD on top of the structure will affect the structure response during earthquake. The result will be compare base on same motion level; arrangement 1 will be compare with arrangement 3, arrangement 2 will be compare with arrangement 4.

A. Water Tanks (Multiple Tuned Liquid Damper)

Roof displacement of the structure with ¾ water level were compared for arrangement 1,2,3 and 4 base on the same motion level, results was summarize in **Table- II** and **Table- III**.

Table- II: Arrangement 1 and 3 for base and top displacement

Arrangement	Motion Level	Base Linear Displacement (mm)	Top Linear Displacement (mm)
1	1	8.912	13.110
	3	4.748	7.837
	5	4.492	6.910
	7	2.202	4.368
	9	0.312	0.997
3	1	8.908	13.894
	3	4.702	7.759
	5	4.290	7.190
	7	2.140	4.460
	9	0.376	1.226

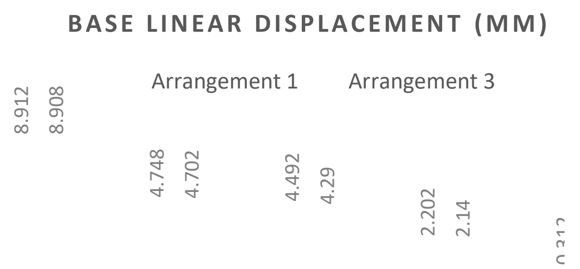

Fig. 5. Comparison Base Linear Displacement between Arrangement 1 and 3

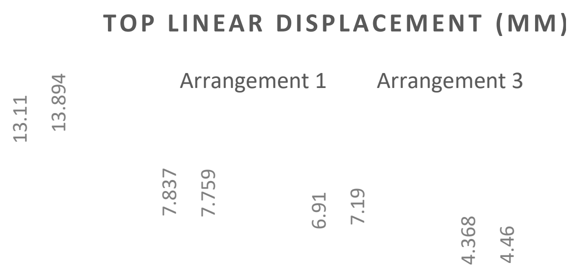

Fig. 6. Comparison Top Linear Displacement between Arrangement 1 and 3

Fig. 5 and **Fig. 6** shows the differences for base and top linear displacement for arrangement 1 and 3. From the **Fig. 5**, the significant different can be seen at level 5 where the differences is 4.6% or 0.202 mm. This shows arrangement 3 during level 5 testing has significant impact towards structure reduction. This situation had effect the top linear displacement as well.

However, for top linear displacement, it is vice versa where arrangement 1 shows less displacement which is 0.28 mm differences compare to arrangement 3 during level 5 testing.

Table- III: Arrangement 2 and 4 for base and top displacement

Arrangement	Motion Level	Base Linear Displacement (mm)	Top Linear Displacement (mm)
2	2	10.452	15.733
	4	6.300	9.456
	6	2.720	4.343
	8	1.370	5.211
	10	0.524	1.711
4	2	10.500	15.996
	4	6.280	9.383
	6	2.822	4.309
	8	1.348	5.530
	10	0.612	1.422

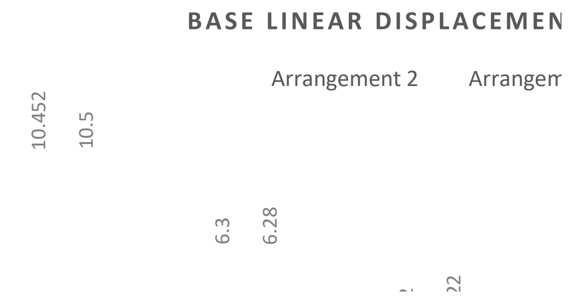

Fig. 7. Comparison Base Linear Displacement between Arrangement 2 and 4

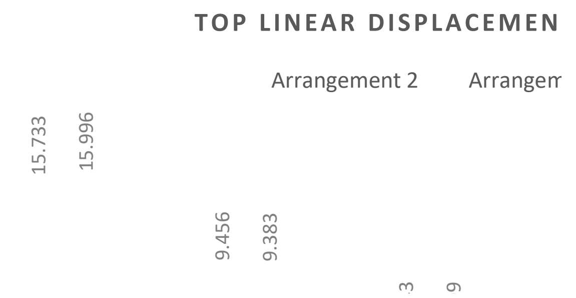

Fig. 8. Comparison Top Linear Displacement between Arrangement 2 and 4

Fig. 7 shows comparison base linear displacement between arrangement 2 and 4 however there is no significant differences between both arrangements for every tested level. Fig. 8 shows arrangement 2 has a slightly better top linear displacement reduction at level 2 and 8 compare to arrange 4 where has better performance at three testing level; 4,6 and 10

B. Acceleration

Table- IV and **Table- V** show the summary of base and top peak acceleration. Base on **Fig. 9** and **Fig. 10**, it can be conclude that there is not much differences for base and top peak acceleration for arrangement 1 and 3. **Fig. 11** shows only level 10 has the big differences impact for base peak acceleration where arrangement 2 is only 5.475 m/s^2 compare to arrangement 4 which is 9.328 m/s^2. However, for top peak acceleration for arrangement 2 and 4 shown in **Fig. 12**, each tested level shows the differences. Arrangement 2 shows the better performance during level 8 testing however arrangement 4 was better during level 10.

Table- IV: Arrangement 1 and 3 for base and top acceleration

Arrangement	Motion Level	Base Peak Acceleration (m/s^2)	Top Peak Acceleration (m/s^2)
1	1	7.344	8.174
	3	10.998	15.548
	5	12.877	17.196
	7	14.737	14.914
	9	4.492	10.892
3	1	7.039	7.971
	3	11.742	16.010
	5	12.924	16.878
	7	14.508	14.555
	9	4.807	11.114

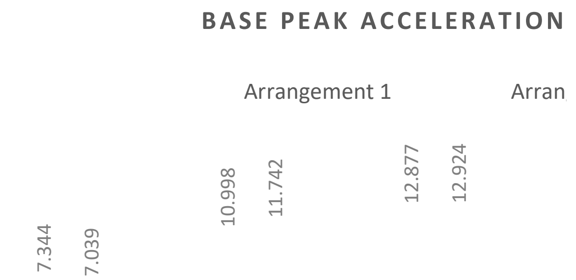

Fig. 9. Comparison Base Peak Acceleration between Arrangement 1 and 3

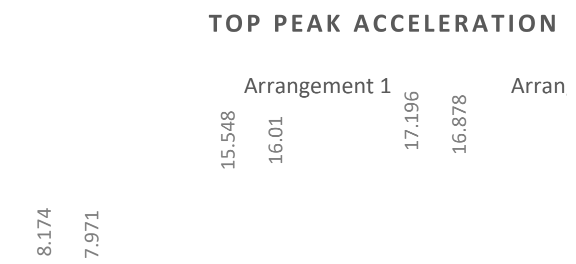

Fig. 10. Comparison Top Linear Displacement between Arrangement 1 and 3

Table- V: Arrangement 2 and 4 for base and top acceleration

Arrangement	Motion Level	Base Peak Acceleration (m/s^2)	Top Peak Acceleration (m/s^2)
2	2	15.967	14.343
	4	11.827	12.849
	6	14.937	11.490
	8	14.708	21.524
	10	5.475	18.208
4	2	15.805	13.273
	4	12.075	11.596
	6	15.547	12.319
	8	14.555	24.811
	10	9.328	14.160

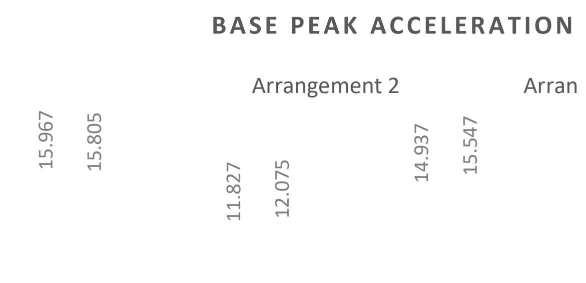

Fig. 11. Comparison Base Peak Acceleration between Arrangement 2 and 4

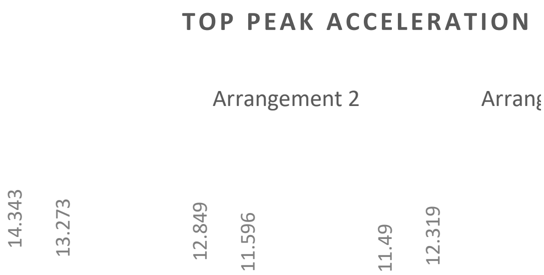

Fig. 12. Comparison Top Peak Acceleration between Arrangement 2 and 4

IV. CONCLUSION

From the analysis, it was founded that different arrangement of water tanks as passive damper at the top of structure gave just slightly differences in displacement and acceleration of the structure where only certain arrangement at certain motion level showed big gap of impact such as top linear displacement for arrangement 1 and 3 at level 1. Referring to **Table- I**, level 1 has a criteria of large displacement and very low aggressiveness.

For acceleration reduction, it founded that at higher level of testing, level 8 and 10 gave the big differences between arrangement 2 and 4. These level 8 and 10 have criteria of short displacement but very aggressive. For others level there were no significant differences between the MTLD arrangements.

Further research need to be conducted so that all four arrangements of MTLD can be compare at the same motion level from level 1 until level 10. Due to expensive of shaking table testing, the aid of analysis software can be used after the validation process taking place.

ACKNOWLEDGEMENT

The authors would like to acknowledge that this research has been carried out as part of a project Bestari Perdana Research Grant with File No 600-IRMI/PERDANA 5/3 BESTARI (078/2018) internal fund, funded by Universiti Teknologi MARA (UiTM) and support from Faculty of Civil Engineering, Universiti Teknologi MARA (UiTM).

REFERENCES

1. A. Adnan, A. Marto, and Hendriyawan, "Lesson Learned From the Effect of Recent Far Field Sumatra Earthquakes to Peninsular Malaysia," 13th World Conf. Earthq. Eng. Vancouver Canada, no. 416, pp. 1–10, 2004.
2. N. H. A. Hamid, S. Anuar, H. Awang, and M. K. Effendi, "Seismic Behavior of Tunnel Form Building under Lateral Cyclic Loading," J. Eng. Technol. Sci., vol. 50, no. 2, pp. 224–239, 2018.
3. N. M. Amin, W. N. A. Sulaiman, A. Jamadin, and A. Alisibramulisi, "Seismic Response Analysis Of 3d Finite Element Bridge Model Using Time History Loading," Int. J. Civ. Eng. Technol., vol. 9, no. 7, pp. 430–436, 2018.
4. R. S. Meshram and S. N. Khante, "Effectiveness of Water Tank as Passive TMD for RCC Buildings," Int. J. Eng. Res., vol. 5013, no. 5, pp. 731–736, 2016.
5. E. Bhattacharjee, L. Halder, and R. P. Sharma, "An experimental study on tuned liquid damper for mitigation of structural response," Int. J. Adv. Struct. Eng., vol. 5, no. 1, pp. 1–8, 2013.
6. T. Wakahara, T. Ohyama, and K. Fujii, "Suppression of wind-induced vibration of a tall building using Tuned Liquid Damper," J. Wind Eng. Ind. Aerodyn., vol. 43, no. 1–3, pp. 1895–1906, 1992.
7. G. Chen and J. Wu, "Experimental study on multiple tuned mass dampers to reduce seismic responses of a three-storey building structure," Earthq. Eng. Struct. Dyn., vol. 32, no. 5, pp. 793–810, 2003.
8. T. S. Gulve and P. Murnal, "Feasibility of Implementing Water Tank as Passive Tuned Mass Damper," Int. J. Innov. Technol. Explor. Eng., vol. 3, no. 3, pp. 12–19, 2013.
9. J. S. Love and M. J. Tait, "Multiple Tuned Liquid Dampers for Efficient and Robust Structural Control," J. Struct. Eng., vol. 141, no. 12, p. 04015045, 2015.
10. Y. M. Kim, K. P. You, N. H. Ko, and S. W. Yoon, "Use of TLD and MTLD for control of wind-induced vibration of tall buildings," J. Mech. Sci. Technol., vol. 20, no. 9, pp. 1346–1354, 2006.

AUTHORS PROFILE

Izzul Syazwan Ishak is a third-year Ph.D student in earthquake engineering, where he is working on the arrangement of multiple water tanks as a passive damper in reducing structure response due to base excitation. He received Bachelor of Engineering (Hons) in Civil Engineering at Universiti Teknologi Petronas in year 2011 under Petronas scholarship and Master of Science in structural engineering from the Universiti Teknologi Mara (UiTM) Shah Alam, Selangor Malaysia, in 2016. He also had an experience became a research assistant and conducting a software classes. His current research interests includes multiple tuned liquid damper, earthquake, structure response and numerical analysis.

Dr. Norliyati Mohd Amin is a Head of Structural and Material Division at the Faculty of Civil Engineering in Universiti Teknologi Mara (UiTM) Shah Alam, Selangor, Malaysia. She is also a graduate engineer at Board of Engineers Malaysia (BEM) and a graduate member at The Institution of Engineers Malaysia (IEM) since 2001. She obtained her Bachelor's degree in Civil Engineering from Kyushu Universiti Japan in 1999. In 2007, she received a Master's degree in Structural Engineering from Universiti Teknologi MARA Malaysia. She obtained a PhD in Structural Engineering from Kyushu University in 2011. She has been serving UiTM since January 2001 as a senior lecturer at the Faculty of Civil Engineering. Her research interest includes computational mechanics, Finite Element Method, modal analysis method and seismic engineering. She has published more than 100 peer review research articles, a book and 4 book chapters. She has received several rewards such as Gold Award in Invention, Innovation & Design Exposition (IIDEX 2016) for "OHME-LAB" and Gold Medal in Malaysia Technology Expo 2017 for "EquakeWPS Wall Panel".

Associate Professor Dr Norhayati Abd. Hamid, is a Deputy Director II at Institute for Infrastructure of Engineering and Sustainable Management (IIESM), UiTM, Shah Alam, Selangor, Malaysia. She is also an associate members of Persatuan Konkrit Malaysia and graduate member of Institute Jurutera Malaysia. She obtained her BSc in Civil Engineering (Hons) in year 1989 at University of Pittsburgh, Pennsylvania, United States of America. In 1991, she received a MSc in Civil Engineering (Construction Management and Structural Engineering) from University of NewCastle Upon Tyne, New Castle, United Kingdom. She obtained a PhD in Earthquake Engineering from University of Canterbury, Christchurch, New Zealand in 2006. Her main current research areas includes Structural Dynamics, Earthquake Engineering, Beam-column joint with corbel and Wall-slab connection for Industrialized Building System (IBS). She has published more than 100 peer review research articles and 13 books/monographs/chapter in books. She has received several awards such Patent the product by the name "equakeWPS" wall panel and gold medal for Institute of Research Development and Commercialization, UiTM (IDD Competition).