CSCE Annual Conference
Growing with youth – Croître avec les jeunes

Laval (Greater Laval)
June 12 – 15, 2019

CASE STUDY OF PERFORMANCE OF A TUNED MASS DAMPER WITH AN EDDY CURRENT DAMPING SYSTEM FOR BUILDING MOTION CONTROL IN WIND

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1 PROJECT OVERVIEW

A 1000 tonne tuned mass damper (TMD) was installed in a high-rise building in Shanghai, China. The TMD was designed not only to reduce building motion in wind but also to be an architecture feature. An eddy current damping system was developed to be the energy-dissipating mechanism for the TMD. The TMD has been in service since 2016. Five typhoons affected Shanghai between July and August 2018. The accelerations of the building and the TMD were recorded during two of the typhoons to verify the TMD performance. The measured results indicate that the TMD performed as expected during the typhoons.

2 INNOVATION – IMPLEMENTATION OF TMD

TMDs have been successfully implemented in numerous high-rise buildings to improve occupant comfort during high winds. A TMD is a secondary dynamic system generally installed near top of a high-rise building. It consists of three key elements including mass, stiffness and damping. A TMD reduces the building motion in wind by moving out-of-phase with the building motion. As the TMD moves, the energy is dissipated through the damping mechanism of the TMD. A TMD's performance depends on several parameters such as TMD mass, TMD frequency and damping characteristic of the TMD. The optimal TMD parameters can be obtained by performing dynamic analysis of the TMD-building system. A 1000 tonne TMD was installed in Shanghai Tower to reduce the building accelerations in wind and to be an architectural feature as well. An eddy current damping system was developed to be the damping mechanism for the TMD. A large array of magnets was attached to move with the TMD mass and a layer of copper plate was fixed to the floor. As the TMD travels back and forth, eddy currents are passively formed in the copper that create a force that resists the motion of the TMD mass relative to the tower, and thus dissipates energy. Figure 1a and 1b show Shanghai Tower, the TMD configuration, the architectural sculpture on the TMD and the eddy current damping system. A dynamic analysis was performed to optimize the TMD performance. The TMD is designed to increase the structural damping ratio from 1% to 3% of critical. This can reduce the building acceleration by approximately 45% to meet the H10 level of AIJ-GEH-2004 criteria for 1-year return period wind events. The tuning and commissioning of the TMD were conducted in 2016. The TMD frequency was tuned to the optimal frequency near the as-built frequency of the tower. The eddy current damping system of the TMD was set to provide the optimal damping force. The TMD has been in service since the tuning and commissioning tasks were completed. Because the TMD is the first high-rise building TMD using eddy current damping system, it is of interest to obtain measured data of the tower and the TMD during wind events to verify the actual TMD performance in service.

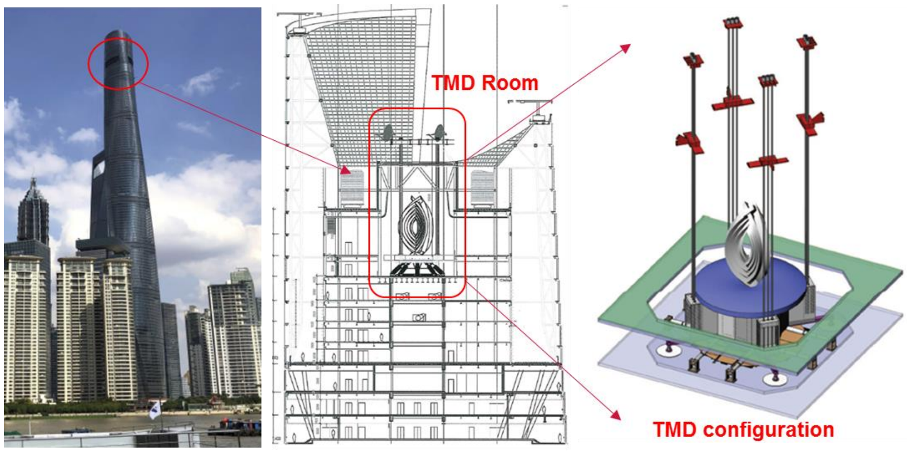

Figure 1a. Shanghai Tower and the TMD configuration

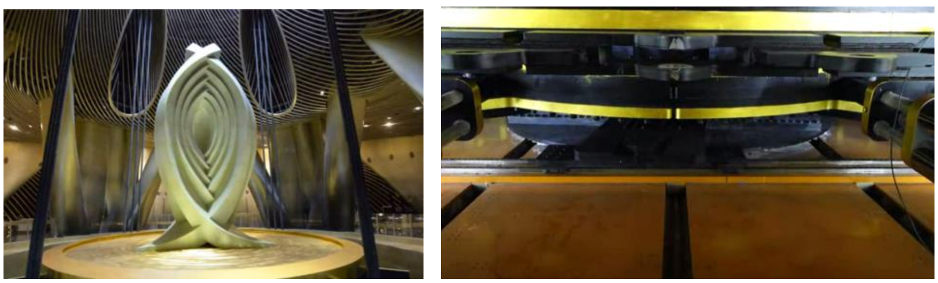

Figure 1b. Architectural piece on the TMD (left photo) and the eddy current damping system (right photo)

3 LESSONS LEARNED – TMD PERFORMANCE VERIFICATION

3.1 TMD released/locked-out test during Typhoon Maria

Five typhoons affected Shanghai between July and August 2018. The wind speeds and the corresponding return periods of the typhoons were analyzed based on the data at Pudong International Airport and are shown in Figure 2. The building accelerations and the TMD accelerations were recorded during Typhoon Maria and Typhoon Ampil in July 2018. The recorded data was analyzed to identify the TMD performance during the events. During Typhoon Maria, the TMD was locked-out and released repeatedly to obtain the building accelerations without and with the TMD. An adjustable damping force device was prepared to create the conditions of locking-out and releasing the TMD; the TMD was deemed to be locked-out when the damping force of the device was switched from near zero to the maximum, effectively stopping relative TMD motion. The TMD was locked-out and released at 10-minute intervals during the period of the recording. Due to the uncertainty of the wind speeds and the wind directionalities, the building could be subjected to different wind loads in each interval. Therefore, the test results are intended to illustrate the intuitive TMD effects but are not used to sharply quantify the TMD performance. Figure 3 shows the acceleration time history of the building and the TMD in the direction of higher response during the event. The blue line indicates when the TMD is released and the red line represents when the TMD is locked-out. The building acceleration and the TMD accelerations during 1000 seconds to 3000 seconds are also shown “zoomed in” in Figure 3. It can be observed that the building peak accelerations with TMD released are approximately 30% lower than with TMD locked-out (at approximately 2000 seconds). In other time periods, the building acceleration is much lower than 1.0 milli-g and the TMD effect is not significant; however, it is not necessary for the TMD to be highly effective because such levels of the vibration (lower than 1.0 milli-g) in the tower is generally imperceptible.

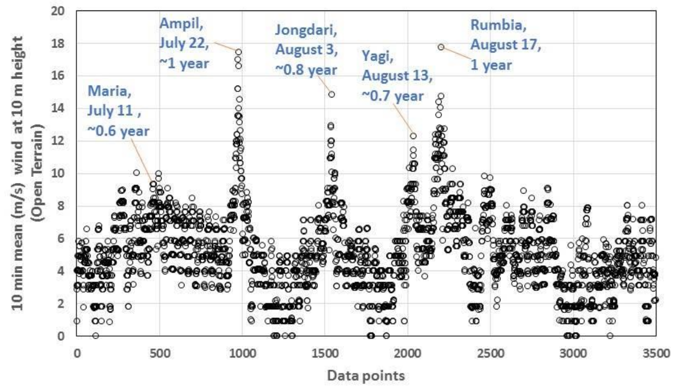

Figure 2. Proceeded wind speed data measured at Pudong international airport

3.2 TMD performance during Typhoon Ampil

One of the design targets of the TMD is to control the building acceleration meeting H10 level of AIJ criteria for 1-year mean recurrence interval (or "return period") wind events. The return period of Typhoon Ampil is approximately one year. The building accelerations and the TMD performance during this typhoon can be considered as a reference case for verifying the TMD performance. The accelerations of the tower and the TMD were recorded during typhoon Ampil on July 22, 2018 from 10:23 to 15:03 (total of 16,800 seconds). The TMD was in normal working condition throughout (no released/locked-out comparison). Figure 4 shows the acceleration time history of the tower and the TMD. It can be observed that the peak total acceleration of the tower was 2.915 milli-g at around 6000 seconds (12:00 am, when typhoon center was closest to the tower, distance was 48 km). and agrees well with the numerically predicted value of 2.8 milli-g. This peak tower acceleration achieved H10 level of AIJ criteria (limit of 3.7 milli-g at 0.1Hz). Figure 5 shows the acceleration time history of the tower and the TMD in X and Y directions. The acceleration of the tower and TMD have a phase difference of 90 degrees, indicating that TMD was working as expected. To quantify the TMD performance, the collected data was analyzed to obtain the effective damping ratio based on the equation [1] (T.T. Soong, and G. F. Dargush, 1997)

[1] $C_{eq} = C + m\frac{<\ddot{z}\dot{y}>}{<\dot{y}^2>}$

Where C_{eq} is total damping of tower; C is building inherent damping; m is TMD mass; z is relative TMD displacement and y is building displacement, and overdots indicate derivative with respect to time. < * > denotes mathematical expectation.

The calculated results indicate that the TMD added approximately 2% effective damping to the tower to achieve a total damping ratio of approximately 3% of critical, which can reduce the tower acceleration by approximately 45%.

4 CONCLUSION

To verify the performance of the TMD installed in Shanghai Tower, a TMD locked-out/released test was conducted during typhoon Maria affecting Shanghai in July 2018. The accelerations of the tower and the TMD during typhoon Ampil in July 2018 were also collected and were analyzed. The analysis results indicate that the TMD added approximately 2% effective damping to the tower to achieve the acceleration criteria. The measured results agreed well with the predicted performance.

Acknowledgments

The authors acknowledge and appreciate the contributions of Shanghai Research Institute of Materials and Shanghai Tower to this case study.

References

T.T. Soong, and G. F. Dargush, 1997. *Passive Energy Dissipation systems in Structural Engineering.* Wiley.

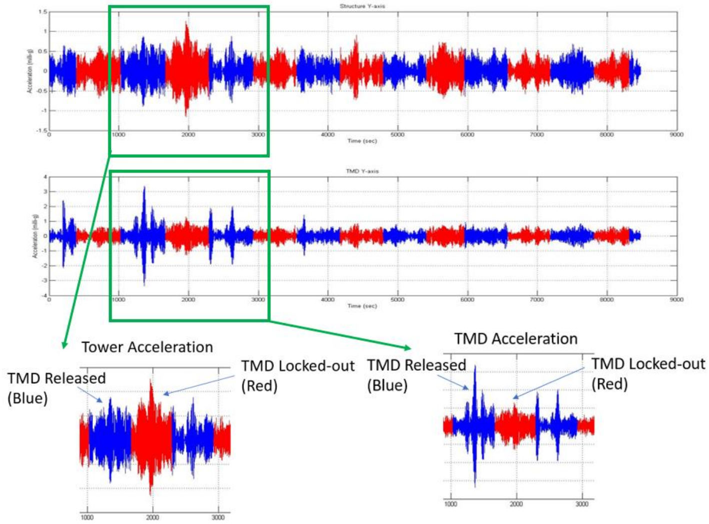

Figure 3. Acceleration time history of the tower and the TMD, Typhoon Maria

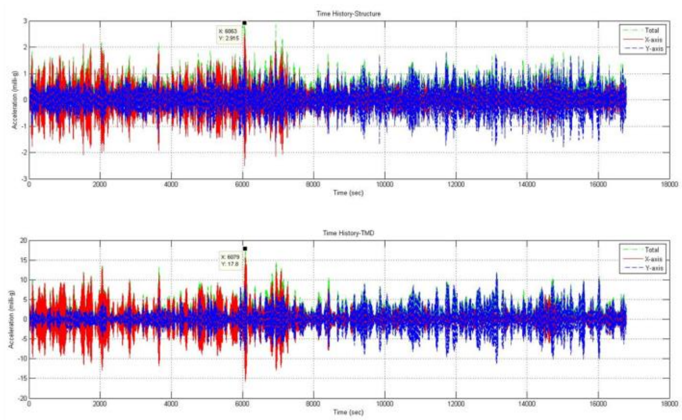

Figure 4. Acceleration time history of the tower and the TMD, Typhoon Ampil

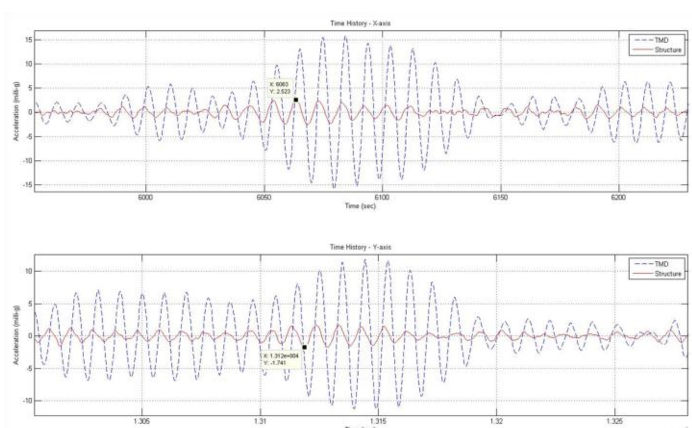

Figure 5. Acceleration time History of the tower and the TMD - Zoom-in, Typhoon Ampil