

TUNED MASS DAMPERS FOR SOLDIER FIELD STADIUM GRANDSTAND VIBRATION

Mal P. Sacks¹, Ramin Behboudi¹, and John C. Swallow²

¹Tacet Engineering Ltd., 45 Denver Cres., Toronto, Ontario, Canada, M2J 1G6, info@tacet.ca

²John Swallow Associates Ltd., 366 Revus Ave., Unit 23, Mississauga, Ontario, Canada, L5G 4S5, jswallow@jsal.ca

1. INTRODUCTION

This paper describes the design and testing of Tuned Mass Dampers (TMD's) for the west grandstand of the newly renovated Soldier Field stadium in Chicago as well as a Permanent Vibration Monitoring System. The stadium is to be used as a venue for both sports and entertainment events.

The state-of-the-art for the reduction of crowd-induced vibration of stadium structures has been extended to include very large systems. Twenty-one TMD's were designed and applied to the upper grandstand perimeter covering almost 1000 linear feet with a total sprung weight of 840,000 pounds. The TMD's are providing impressive reduction of vibration levels in the design frequency range of 1.5 Hz to 2.7 Hz and eliminate virtually all resonant peaks in the 2 Hz to 3 Hz frequency band. Vibration reduction factors are typically in the range of 3 to 10. The success of the project was based on a unique configuration of spring systems to achieve flexibility in the design and field tuning.

A purpose-built 64-channel Permanent Vibration monitoring System was also supplied for future TMD testing, on-going maintenance and to facilitate administrative control of vibration.

2. PROBLEM DEFINITION

The prior existing stadium was a designated historic building. This required that the existing façade be retained which, in turn, resulted in the top of the west grandstand being cantilevered out 40 feet beyond the column supports.

Finite element analysis of the upper west grandstand indicated vibration levels in excess of established limits due to crowd-induced dynamic loadings. Criteria were established for vibration level limits based on spectator comfort (i.e., structural integrity was not an issue).

Given the unique geometrical constraints of this grandstand, it was not possible to stiffen the structure sufficiently to achieve acceptable vibration levels. Consequently, the addition of a vibration damping system was required and TMD's were chosen. FE analysis indicated that TMD's would reduce vibration levels to below accepted values. Use of TMD's is typically cost effective because the same reduction in vibration amplitude through increased stiffness

would require very much larger structural framing which would not be practical and, in the case of this grandstand, not possible.

3. TMD DESIGN

Given the design constraints, the only way to achieve the required mass was in the form of a beam spanning the approximately 40 foot to 50 foot variable distance between rakers. A total of 21 TMD's are located at the top of the west grandstand spanning between the 22 raker girders. The TMD mass consists of a beam constructed as a steel box filled with concrete. The beam lengths vary from approximately 25 feet to 35 feet, are 17 inches deep and have a vertical height calculated to produce a total sprung weight of 40 kips; i.e. the height varies from approximately 4 feet to 6 feet. At each end of the mass beam is a yoke, i.e. a large horizontal U-shaped bracket, which mates with a cantilevered horizontal stub beam attached to the vertical upstand at the tip of the raker.

Support for the mass beam was provided by air springs and steel springs located between the stub beam and yoke. Energy dissipation is provided hydraulic cylinders supplied by Taylor Devices Inc., North Tonawanda, NY and are called Taylor dampers or dashpots. The dashpots are installed between the free end of the stub beam and upper arm of the yoke and can be adjusted to achieve desired TMD damping ratios. Two guide wheels are attached to the free ends of both the upper and lower arms of the yoke. These wheels run on vertical V-tracks attached to the raker upstand. These guide wheels provide stability for the air springs and constrain the mass beam vibration to vertical motion.

The spring system must provide the precise stiffness required and also support the dead load of the TMD while maintaining precise clearances required for TMD operation at tuning frequencies that may be changed in-situ at any time. These multiple requirements are resolved in a unique way by providing two spring systems. Industrial pneumatic springs, installed between the stub beam and upper yoke arm, support the dead load while providing a very low stiffness. The additional stiffness required to achieve the TMD tuning frequency is supplied by small non-load bearing helical steel springs installed between the stub beam and lower yoke arm, in parallel with the pneumatic springs. All TMD's were required to be tunable to all frequencies

between 1.5 Hz and 2.7 Hz in nominal increments of 0.1 Hz. Tests of a full scale prototype TMD demonstrated the flexibility and reliability of the tuning technique.

The 21 TMD's were tuned alternately to 1.5 Hz and 2.7 Hz with damping ratios from 0.06 to 0.13 of critical damping as determined by the FE analysis.

4. TMD TESTING

4.1 TMD Calibration Tests

A replica of TMD #12 was fabricated and assembled in a calibration test rig in order to be closely examined and tuned to various frequencies and damping ratios required in actual field operation. (Fig. 1)

A quick release mechanism was designed and used to displace the TMD and instantaneously release it in order to excite the system to vibrate at its natural frequency. Acceleration traces from accelerometers mounted on the TMD were digitized and processed in order to find system natural frequencies and damping ratios corresponding to various spring combinations and damper settings.

4.2 Stadium Vibration Tests

Vibration tests were conducted on the west grandstand in June 2003 using a vibration shaker purpose built by Anco Engineers, Inc., Boulder, Colorado. The shaker is capable of producing a vertical force with a maximum amplitude of 2000 pounds at any frequency in the range of 1 Hz to 5 Hz. For comparison note that a 2000 pound dynamic force amplitude is equivalent to the force amplitude produced by about a dozen adults performing vigorous aerobic exercise, e.g. synchronized jumping jacks.

4.3 Permanent Vibration Monitoring System

Stadium vibration measurements were obtained using the Permanent Vibration Monitoring System (PVMS) specifically designed for this project. This system consists of 64 accelerometers hard wired to a central data acquisition system. The data acquisition system consists of a 64 channel signal conditioner, 64 channel data acquisition board and a desktop computer that runs the purpose built software developed for this system to measure and display vibration magnitudes and phases for each accelerometer. The PVMS can be remotely operated through the internet.

One accelerometer is located at each end of each TMD (21 x 2) and one at each raker adjacent to the TMD's (22) for a total of 64. The accelerometers are aligned to measure vertical vibration which is consistent with the vertical operation of the TMD's.

The tests demonstrated that the TMD's are performing in accordance with their design criteria; i.e. the TMD's are providing significant reduction of vibration levels in the

design frequency range of 1.5 Hz to 2.7 Hz and eliminate virtually all resonant peaks in the 2 Hz to 3 Hz frequency band. Vibration reduction factors are typically in the range of 3 to 10. (Fig. 2)

REFERENCES

Sacks, M.P. and Swallow, J.C. (1993). Tuned Mass Dampers for Towers and Buildings. Proceedings of the ASCE Structures Congress '93, vol. 1, p. 640-645.

Burns, J.G. and McLean, D.P. (2004). Field Goals. Modern Steel Construction, July 2004.

Burns, J.G. and McLean, D.P. (2005). Adaptive Reuse of Soldier Field Chicago. Modern Steel Construction, May 2005.

Reynolds, P., Pavic, A. and Ibrahim, Z. (2003). A Remote Monitoring System for Stadia Dynamics. 21st International Modal Analysis Conference, Florida, USA, February 2003.



Fig. 1. Prototype TMD ready for calibration.

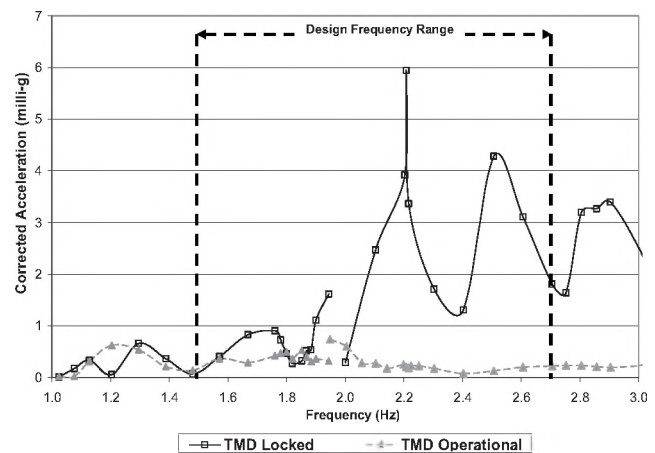


Fig. 2. Sample plot showing effectiveness of the installed TMD's.