International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 13 Issue: 06 | Jun 2026 www.irjet.net p-ISSN: 2395-0072

A Review on Performance Assessment of Distributed Tuned Mass Dampers for Wind Response Control of Tall Buildings Using CFD and Structural Dynamic Analysis

Mitesh R. Sakpal[1], P. J. Salunke[2]

[1]PG Student, Dept of civil engineering, Mahatma Gandhi Mission's College of Engineering and Technology(MGMCET), Kamothe, Navi Mumbai, Maharashtra, India
[2]Professor, Dept of civil engineering, Mahatma Gandhi Mission's College of Engineering and Technology(MGMCET), Kamothe, Navi Mumbai, Maharashtra, India

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Abstract-*The increasing construction of tall and slender buildings has intensified the challenges associated with wind-induced vibrations. Excessive lateral displacements and accelerations generated by aerodynamic forces can adversely affect occupant comfort, structural serviceability, and long-term performance. Conventional wind-resistant design methods primarily rely on codal provisions and wind tunnel experiments; however, recent advances in Computational Fluid Dynamics (CFD) have enabled detailed simulation of atmospheric boundary layer flow and aerodynamic loading on buildings. Simultaneously, vibration control devices such as Tuned Mass Dampers (TMDs) have become widely adopted for mitigating dynamic responses. Although single TMD systems are effective near the fundamental frequency, their efficiency decreases when higher vibration modes significantly contribute to structural behavior. To overcome these limitations, Distributed Tuned Mass Dampers (d-TMDs) have been proposed, where multiple dampers are strategically distributed along the building height and tuned to different modal frequencies. This review presents a comprehensive assessment of previous studies related to CFD-based wind load prediction, wind-induced response of tall buildings, multiple and distributed tuned mass dampers, and coupled aerodynamic-structural analyses. The findings indicate that d-TMD systems provide superior vibration mitigation and robustness compared to conventional TMD configurations. Furthermore, integrating CFD-derived wind loads with structural dynamic analysis offers a realistic framework for evaluating vibration control performance. The review also identifies major research gaps and future opportunities for enhancing wind response mitigation strategies in tall buildings.*

Keywords: [Computational Fluid Dynamics, Distributed Tuned Mass Dampers, Tall Buildings, Wind-Induced Vibrations, Structural Dynamics, Wind Engineering, CFD-ETABS Coupling.]

I.INTRODUCTION

Rapid urbanization and the growing demand for high-rise infrastructure have resulted in the construction of increasingly tall and slender buildings. While advancements in construction materials and structural systems have enabled greater heights, they have also increased susceptibility to dynamic environmental loads, particularly wind. Unlike gravity loads, wind loads are highly variable and can induce significant lateral displacements, accelerations, and torsional responses.

For modern tall buildings, serviceability criteria often govern design rather than strength requirements. Excessive building accelerations may cause occupant discomfort even when structural safety remains unaffected. Consequently, understanding wind–structure interaction and developing efficient vibration control systems have become essential aspects of structural engineering.

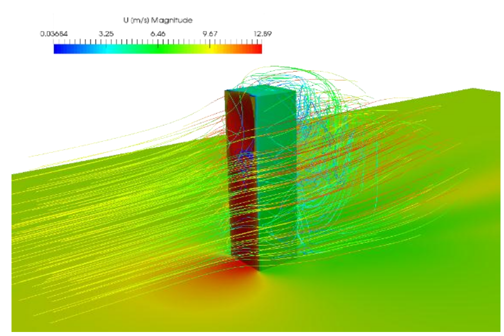

Fig 1. CFD Analysis- Flow around the building.

Traditionally, wind effects have been evaluated through wind tunnel testing and empirical codal procedures. Although these methods provide reliable estimates, they are often expensive, time-consuming, and limited in capturing detailed flow physics. Computational Fluid

Dynamics (CFD) has emerged as a powerful alternative capable of simulating atmospheric boundary layer flow, vortex shedding, wake formation, and pressure distributions around complex geometries.

In parallel, structural vibration control systems have evolved significantly. Among passive control devices, Tuned Mass Dampers (TMDs) have demonstrated effectiveness in reducing dynamic responses. However, conventional single TMD systems are generally tuned to the fundamental mode and may become ineffective under multi-modal excitation. To address this limitation, researchers have developed Multiple Tuned Mass Dampers (MTMDs) and Distributed Tuned Mass Dampers (d-TMDs), which distribute damping capacity across several vibration modes.

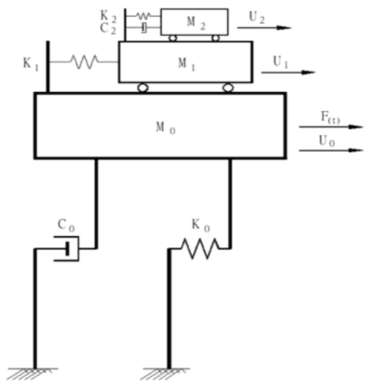

Fig 2. Analysis model of the DTMD-structure system

The integration of CFD-generated wind loading with structural dynamic analysis provides an advanced methodology for evaluating d-TMD performance under realistic wind conditions. This review examines previous developments in CFD-based wind analysis, vibration control technologies, and their combined application for improving the serviceability performance of tall buildings.

II.LITERATURE SURVEY

- **Ormondroyd and Den Hartog (1928)** introduced the dynamic vibration absorber concept and demonstrated that a secondary tuned mass could effectively suppress resonant vibrations in a primary structure. Their work established the theoretical basis for passive vibration control systems.

- **Den Hartog (1956)** further developed vibration absorber theory by introducing analytical formulations for optimum tuning and damping parameters. These principles remain the foundation of modern tuned mass damper design.

- **Ayorinde and Warburton (1980)** investigated vibration absorbers for dynamically complex systems and showed that optimum damper parameters differ significantly from classical single-degree-of-freedom assumptions when multiple vibration modes participate in the response.

- **Xu and Igusa (1992)** examined structures equipped with numerous attached oscillators and demonstrated that distributed auxiliary masses collectively behave as an equivalent damping mechanism. Their findings provided the theoretical basis for distributed tuned mass damper systems.

- **Chen and Wu (2001)** evaluated multiple tuned mass dampers for seismic vibration control and reported acceleration reductions significantly greater than those achieved by a single TMD of equivalent total mass.

- **Bakre and Jangid (2004)** optimized multiple tuned mass damper configurations and demonstrated superior vibration reduction under harmonic excitations compared with conventional single-damper systems.

- **Yang et al. (2004)** established a benchmark problem for a 76-storey wind-sensitive building and provided a standardized platform for evaluating active, passive, and semi-active vibration control systems under wind loading.

- **Samali et al. (2004)** conducted extensive wind tunnel experiments on the benchmark building and generated reliable across-wind force data used in subsequent vibration control investigations.

- **Patil and Jangid (2011)** investigated multiple tuned mass dampers installed at the roof level of a benchmark tall building and observed improved robustness and response reduction compared to single TMD systems.

- **Bourgeois et al. (2011)** experimentally studied turbulent flow around a finite square cylinder and identified the large-scale vortex structures responsible for aerodynamic force fluctuations. Their findings provided valuable validation data for CFD studies.

- **Wang et al. (2011)** numerically simulated turbulent flow around a wall-mounted square cylinder using Reynolds Stress Models and successfully reproduced major flow structures including horseshoe vortices, tip vortices, and wake formations.

- **Davis et al. (2012)** compared various RANS turbulence models and concluded that the realizable k–ε model produced the most accurate predictions of mean flow behaviour and pressure distributions for bluff-body aerodynamics.

- **Bourgeois et al. (2013)** extended their wake investigations by reconstructing three-dimensional flow fields using advanced phase-averaging techniques and highlighted the importance of coherent vortex structures in wind loading.

- **Saeedi et al. (2014)** performed Direct Numerical Simulation (DNS) to investigate turbulence production around finite square cylinders and demonstrated the significant influence of boundary-layer interactions on wake dynamics.

- **Elias and Matsagar (2014)** investigated distributed multiple tuned mass dampers for wind-sensitive tall buildings and reported substantial reductions in displacement and acceleration responses when dampers were distributed according to modal participation factors.

- **Saeedi and Wang (2016)** employed Large Eddy Simulation (LES) to study turbulent wake development and identified dominant turbulence production zones responsible for aerodynamic force fluctuations.

Recent studies have increasingly emphasized the integration of CFD with structural dynamic analysis. Researchers have demonstrated that CFD-derived force histories provide more realistic wind loading than simplified codal approaches. However, investigations combining CFD-generated loads with distributed tuned mass damper systems remain relatively limited.

III.SUMMARY OF LITERATURE REVIEW

The following conclusions can be drawn from the reviewed studies:

1. Wind-induced vibrations significantly influence the serviceability performance of tall buildings.

2. CFD has become an effective tool for predicting aerodynamic pressures, drag forces, lift forces, vortex shedding behaviour, and wake characteristics.

3. Turbulence modelling approaches such as URANS, LES, and DNS have demonstrated varying levels of accuracy in simulating bluff-body aerodynamics.

4. Conventional single tuned mass dampers are effective only within a limited frequency range and are sensitive to mistuning.

5. Multiple and distributed tuned mass damper systems provide improved robustness and superior vibration mitigation compared to single TMDs.

6. Strategic damper placement based on modal participation enhances structural response reduction.

7. CFD-generated force histories enable realistic representation of wind loading conditions.

8. Coupled CFD–structural dynamic analysis frameworks offer significant potential for evaluating advanced vibration control systems.

9. Distributed tuned mass dampers are particularly suitable for tall buildings exhibiting multi-modal dynamic behaviour.

10. The combination of CFD-derived wind loads and d-TMD systems represents a promising approach for improving tall-building serviceability performance.

IV.GAPS IN LITERATURE REVIEW

Despite considerable progress in wind engineering and vibration control research, several important gaps remain:

1. Most studies investigate CFD simulations and vibration control systems independently rather than through a fully integrated framework.

2. Limited research has been conducted on d-TMD performance under CFD-derived wind force time histories.

3. The majority of TMD investigations utilize simplified analytical or wind tunnel loads rather

than realistic aerodynamic force histories obtained from CFD.

4. Few studies evaluate d-TMD effectiveness in controlling displacement, acceleration, and story drift simultaneously.

5. Research addressing optimal vertical distribution of dampers under realistic modal participation conditions remains limited.

6. The influence of drag and lift force fluctuations extracted directly from CFD simulations on damper performance has not been comprehensively investigated.

7. Practical implementation of d-TMD systems in ETABS using CFD-generated loading functions has received limited attention.

8. Few studies focus on medium-height reinforced concrete buildings (G+20 range) subjected to CFD-based wind loading.
9. Comparative studies examining structures with and without d-TMD systems under identical CFD loading conditions are scarce.

10. A comprehensive CFD–ETABS–d-TMD methodology for wind response control remains insufficiently explored and requires further investigation.

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