# Active Control System: A Comprehensive Review

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***Abstract*—This study offers a thorough analysis of the different control systems and techniques used in structural engineering, emphasizing the mitigation of dynamic actions like severe winds and earthquakes. The study explores the implementation of active, semi-active, and hybrid control systems in civil engineering structures to enhance their resilience against dynamic forces. Traditional approaches to reducing vibrations, such as building structures with resistance and ductility, are compared with newer concepts of structural control. The paper discusses the development and application of passive, active, hybrid, and semi-active control systems, highlighting their advantages, limitations, and real-world implementations. Furthermore, it explores recent advancements in smart structures and control technologies, including the usage of magnetorheological (MR) dampers, piezoelectric actuators, and fuzzy supervisory control approaches. Experimental validations and numerical simulations are employed to assess the efficiency and performance of these control strategies. Overall, the paper contributes to the understanding of structural control methodologies and their implications for enhancing the safety and resilience of civil engineering structures against dynamic forces.**

***Keywords—Active Control, Earthquakes, Structural Control, Semi-active control, Sensors.***

## I. INTRODUCTION

Structural engineering encompasses a broad spectrum of methodologies aimed at ensuring the safety, stability, and resilience of civil engineering structures against various dynamic actions, including earthquakes and severe winds. With the increasing complexity of modern structures and the growing demand for enhanced performance and safety standards, the development and implementation of effective control strategies have become imperative. Traditional approaches to mitigating structural vibrations and dynamic forces often revolve around the design and construction of bridges and buildings with inherent resistance and ductility. While these methods have been successful to some extent, they may not always provide optimal solutions, especially in scenarios where extreme dynamic events pose significant challenges. In recent years, there has been a paradigm shift in the field of structural engineering toward the adoption of advanced control systems. These systems, which include active, semi-active, and hybrid control strategies, offer a proactive approach to managing structural responses to dynamic forces. By actively modulating structural properties or applying external forces in real-time, these control systems can effectively reduce vibrations, minimize structural damage, and improve overall performance. The adoption of active control systems involves the use of actuators and sensors to actively apply controlled forces to the structure in response to dynamic inputs. These systems require a continuous power source and real-time monitoring of structural conditions, allowing for precise regulation of structural responses. Semi-active control systems, on the other hand, offer a more energy-efficient alternative by dynamically adjusting damping properties or stiffness characteristics based on structural conditions. Active and passive control strategies are combined in hybrid control systems to maximize efficiency and reduce energy usage. The development of advanced control systems in structural engineering has been driven by significant advancements in control algorithms, sensing technologies, and actuator designs. These advancements have enabled researchers and engineers to explore innovative approaches to structural control, such as model predictive control, fuzzy logic control, and adaptive control techniques. Despite the progress made in theoretical research and algorithm development, there remains a gap between theoretical concepts and practical implementations. Experimental validations and real-world deployments of advanced control systems are essential to bridge this gap and demonstrate these technologies' viability and efficiency in real-world applications. In this regard, the goal of this paper is to present a thorough overview of the most advanced structural control systems available today for mitigating dynamic actions. The goal of the paper is to clarify the benefits, drawbacks, and possible uses of active, semi-active, and hybrid control systems in civil engineering structures by reviewing relevant research and case studies. Furthermore, the paper aims to identify research gaps and future directions for the progress and implementation of advanced control systems in structural engineering

## II. NEED OF THE STUDY

The study addresses several critical needs in the field of structural engineering. Firstly, it aims to enhance structural safety, particularly in the context of dynamic actions like earthquakes and severe winds, which pose significant threats to civil engineering structures. Secondly, the study seeks to optimize structural performance by exploring advanced control strategies tailored to minimize dynamic responses. Notably, traditional approaches to structural design may fall short in providing optimal solutions under varying dynamic conditions, hence the necessity for innovative control systems. Thirdly, the study aims to bridge the gap between theoretical concepts and practical implementations in control systems. Despite notable advancements in control algorithms and technologies, there remains a gap that experimental validations and real-world deployments can address, ensuring the effectiveness and feasibility of these systems. Furthermore, the study addresses the emerging challenges faced by the structural engineering community, such as increasing structural complexity and changing environmental conditions, by proposing innovative solutions to ensure the resilience of civil engineering structures. Lastly, the study emphasizes the importance of improving the efficiency of control systems. Leveraging emerging technologies like machine learning (ML), artificial intelligence (AI), and the Internet of Things (IoT) for real-time monitoring and control can significantly enhance the efficiency of structural control systems, thereby further advancing the safety and stability of civil engineering structures.

## III. REVIEW OF LITERATURE

In this article, the application of an active control system to stop pressure differentials in gasket plate heat exchangers (GPHE) in the gas and oil sector from causing malfunctions is discussed. The goal is to lessen pressure events in the GPHE to reduce mechanical stresses. Controlling the pressure differential between branches can minimize pressure events by roughly 50%, according to the study, which employed a test bench to simulate pressure-related incidents at an oil production plant. The authors propose that slow pressure changes can be further mitigated by adding a control valve in the oil well branch. The findings indicate that adding a control valve to the oil well branch could enhance the best option that was first offered. The study also discusses the implications of neglecting pressure variations in the gas and oil industry, which can lead to severe system malfunctioning and financial losses. The paper provides valuable insights into the importance of active pressure control in preventing heat exchanger malfunctions in the oil and gas industry [1].

The study extensively examines active as well as semi-active control strategies in earthquake engineering within the past decade. It underscores the advancements in control algorithms and their verification through numerical or analytical methods. Despite the strides made in developing intricate algorithms, there remains a notable absence of real-world deployment of these strategies. The authors stress the significance of conducting experimental validations to bridge the divide between theoretical concepts and practical utility. Furthermore, the document references successful installations of active control systems in prominent structures such as the Taipei building in Taiwan and towers in Japan, highlighting the tangible benefits of these technologies. The authors also express their commitment to validating select control algorithms at a research facility at Istanbul Technical University, underscoring the value of experimental investigations in this domain [2].

The paper introduces an integrated active and semi-active control system, named INASA, to address challenges in structural control during earthquakes. The system aims to minimize both active and semi-active control energy, along with structural energies, simultaneously. By incorporating an MR damper with an active tendon controller system, the INASA system shows promising results in reducing structural response to seismic excitations. The study considers time-delay effects and the electrical current requirements for MR damper operation in numerical simulations. A satisfactory uncontrolled response reduction percentage of 20–25% is attained using the active control system. The piece-wise invertible MR damper model used in the system estimates damping force based on input current levels, demonstrating its effectiveness in controlling structural vibrations. The late Professor Mehmet Bakioglu and Professor Jean-Paul Pinelli's contributions to the study are also acknowledged in the report. Overall, the INASA system presents a novel approach to structural control under earthquake excitations, combining active and semi-active control strategies for improved performance as well as energy efficiency [3].

The paper discusses several control strategies for structures, specifically focusing on voltage control laws in the context of magnetorheological (MR) dampers. It highlights comparative studies on control laws, such as inverse on-off voltage law (IOOVL), clipped voltage law (CVL), and inverse quadratic voltage law (IQVL). Additionally, it mentions the benefits of optimal static output feedback (OSOF)–IOOVL/CVL control over passive-on control in terms of reducing peak inter-storey drift, performance index, and RMS inter-storey drift. The article also mentions a simpler proportional and integral (PI) control approach proposed by Aguirre et al. (2011), which exhibits enhanced structural responses and performance on par with algorithms with greater complexity. Furthermore, the paper addresses the use of market-based techniques in wireless structural health monitoring and mode shape estimation along with issues like eigenvalues, time delay, model decomposition, poles, and decentralization in structural control. It also notes the increasing interest in developing non-linear control methods for complex structures and emphasizes the importance of the interaction between modeling and control formulation [4].

The paper examines research on smart structures, specifically focusing on control systems and methods. It discusses various approaches, including active-tuned mass dampers, piezoelectric dampers, and distributed actuators. The experiments with a piezo-driven variable friction damper showed positive results, as it effectively reduced inter-storey drifts and accelerations. The study also highlighted the usage of a TMD-MR system and PZT actuators for vibration control. Additionally, the paper mentions other control devices and methods, such as shape memory alloys and semi-active fluid dampers. The overall goal of the research is to develop effective control strategies that can mitigate vibrations and enhance the performance of structures [5].

This paper reviews the implementation of active and hybrid control systems in civil engineering structures to protect against dynamic actions like earthquakes and severe winds. The traditional approach to reducing vibrations caused by these events is to build structures with resistance and ductility. Nevertheless, the goal of more recent theories of structural control, such as passive, active, hybrid, and semi-active systems, is to completely eradicate inelastic deformations in the structure. Active control systems need a power source and use actuators to apply controlled forces to the structure. Hybrid control systems combine passive and active control devices to enhance performance. Examples of real-world implementations are discussed, highlighting their effectiveness in reducing vibrations and enhancing structural safety [6].

The study investigates the application of magnetorheological (MR) dampers for controlling and strengthening structures by mitigating vibrations. It introduces an explicit preview control system tailored for this purpose and examines how structural characteristics, including damping and stiffness, impact system response and performance. Through this analysis, the study elucidates the influence of different parameters on vibration suppression. Results indicate the proposed control strategy's effectiveness in reducing vibrations within unprotected structures, with the paper detailing specific aspects of the strategy and its outcomes. The implications of these findings are significant for real-world applications, suggesting that implementing MR dampers with the suggested control strategy could enhance the stability and safety of various vibration-prone structures [7].

The paper introduces a hierarchical fuzzy supervisory control approach for actively managing vibrations in earthquake-excited building structures. The control method includes a higher-level supervisor and multiple lower-level sub-controllers. Each sub-controller utilizes optimal control theory to minimize the story drift of individual floors, while a fuzzy logic system is employed to generate an appropriate supervisor. The fuzzy supervisor dynamically adjusts the control gains by utilizing a fuzzy inference mechanism to estimate the state of the structure. Numerical simulations on a three-story structure with an active tendon system are carried out to validate the suggested control strategy.[8].

This research paper examines the current status of active, semi-active, and hybrid structural control systems for mitigating wind and seismic responses in buildings and bridges. It discusses the development of these systems over time, their advantages, limitations, and applications in seismic design and retrofitting of civil engineering structures. The use of sensors, controllers, actuators, and real-time information processing in these systems is also being investigated by the research. Notably, it emphasizes the benefits of active control systems, their integration with passive control technologies, and the potential of semi-active control devices [9].

The paper examines the use of semi-active control systems in guarding structures from earthquake-induced ground motion. It compares passive, active, and semi-active control systems and highlights the advantages of the latter. This paper investigates several semi-active control systems, such as tuned mass dampers, tuned liquid dampers, friction control devices, electrorheological dampers, magnetorheological dampers, and stiffness control devices. The experimental results demonstrate the potential benefits of these systems in improving seismic behavior. Additionally, the paper emphasizes the importance of further research and advancements in control algorithms to improve the performance of semi-active control systems [10].

The main objective of this paper is to analyze the performance and stability of decentralized adaptive feedforward control systems. By utilizing the Gerschgorin circle theorem, the authors derive a stability condition and explore various levels of decentralization in different real-world applications, such as active sound control systems. Additionally, the paper investigates the performance of adaptive feedforward control algorithms in a three-channel active sound control system, considering factors like control system errors and the convergence of decentralized controllers. The experimental results align well with the theoretical predictions, highlighting the efficacy of the decentralized control approach [11].

The study aims to utilize piezoelectric actuators for the control of flexible beams' vibrations. To optimize actuator placement, control gains, and excitation voltage, the authors suggest a technique known as Modified Independent Modal Space Control (MIMSC). The objective is to reduce beam vibration amplitudes and minimize the control effort required. The study considers the impact of actuators and bonding layers on the composite beams' elastic and inertial properties. Numerical examples demonstrate the effectiveness of the MIMSC method in designing active control systems for flexible beams. The study emphasizes the significance of proper actuator placement and the consideration of bonding layer characteristics [12].

## IV. CONCLUSION

The state-of-the-art structural control systems for reducing dynamic actions in civil engineering structures have been thoroughly reviewed in this article. Key discoveries and ideas have been emphasized through a study of relevant research and case studies, which has deepened our understanding of the benefits, limitations, and possible uses of active, semi-active, and hybrid control systems. The adoption of advanced control systems in structural engineering offers promising opportunities to enhance the safety, stability, and resilience of civil engineering structures against dynamic forces like earthquakes and severe winds. By actively modulating structural properties or applying external forces in real-time, these control systems have demonstrated their effectiveness in reducing vibrations, minimizing structural damage, and improving overall performance. The development of advanced control systems has been facilitated by significant advancements in control algorithms, sensing technologies, and actuator designs. These advancements have enabled researchers and engineers to explore innovative approaches to structural control, such as model predictive control, fuzzy logic control, and adaptive control techniques. However, despite the progress made in theoretical research and algorithm development, there remains a gap between theoretical concepts and practical implementations. Experimental validations and real-world deployments of advanced control systems are essential to bridge this gap and demonstrate the possibility and efficiency of these technologies in real-world scenarios. Moving forward, it is imperative to continue research efforts aimed at addressing the remaining challenges and limitations associated with the implementation of advanced control systems in structural engineering. This includes further investigation into the integration of control systems with rising technologies such as ML, AI, and IoT for enhanced performance and efficiency. Overall, the findings presented in this paper underscore the importance of advanced control systems in enhancing the safety, stability, and resilience of civil engineering structures against dynamic actions. By leveraging the latest advancements in control technologies, researchers and engineers can continue to develop innovative solutions to address the evolving challenges faced by the structural engineering community.

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