THE APPLICATION AND PRACTICAL ISSUES OF SEISMIC MONITORING AND HEALTH DIAGNOSTICS FOR STRUCTURES

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1. INTRODUCTION

The seismic resistance of a structure may degrade over time due to material aging, cumulative seismic effects, or damage to structural components, thereby compromising its overall safety. While detailed seismic evaluations remain essential for assessing structural integrity, the frequent occurrence of seismic events makes repeated manual assessments both time-consuming and economically burdensome.

With the increasing maturity and accessibility of structural health monitoring (SHM) technologies, it is now feasible to implement continuous, real-time monitoring of structural parameters. By employing sensors and instrumentation, changes in dynamic characteristics—such as natural frequency and damping ratio—can be tracked continuously, enabling the early identification of potential structural degradation and enhancing post-earthquake diagnostics.

This study presents a framework that integrates the results of detailed seismic evaluations with SHM data and earthquake alerts issued by Taiwan's Central Weather Bureau. Based on this integration, building-specific seismic damage levels are defined and employed to develop a real-time notification system. Upon the occurrence of an earthquake, the system cross-references real-time ground motion data with predefined seismic damage thresholds to evaluate the structure's condition. Furthermore, by monitoring variations in natural frequency during both seismic events and regular operational periods, the system supports ongoing assessments of the building's structural health.

To enhance communication and post-event decision-making, the evaluated seismic damage status and monitoring results are automatically delivered to stakeholders via the Line messaging platform. This user-oriented dissemination mechanism facilitates timely maintenance actions and contributes to a more resilient built environment

.2. LONG-TERM MONITORING OF STRUCTURES

Figure 1 shows the concept of long-term monitoring. Structures currently in service, especially those affected by aging or exhibiting insufficient seismic resistance, are particularly vulnerable to earthquake-induced damage. Given constraints such as limited financial resources, delaying reinforcement and retrofitting projects, long-term structural health monitoring (SHM) combined with effective diagnostic methodologies becomes imperative. Such monitoring systems continuously gather structural response data during seismic events, subsequently transmitting this information to a cloud-based database for systematic archiving and visualization, enabling immediate sensor-specific data analysis. Moreover, advanced diagnostic algorithms are utilized after each seismic event to evaluate whether the structural safety parameters deviate from their predetermined baseline conditions. A principal advantage of this proactive approach is the capability to issue timely warnings about potential structural risks, substantially mitigating human casualties and reducing social and economic repercussions resulting from severe damage or structural failure. Figure 2 shows the monitoring of the earthquake response for structural health assessment processes.

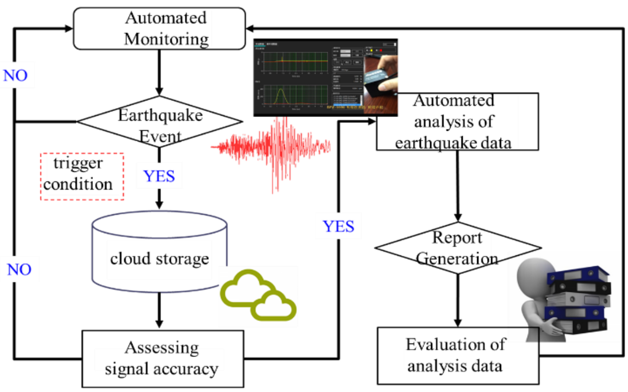

Figure 1. The concept of long-term monitoring

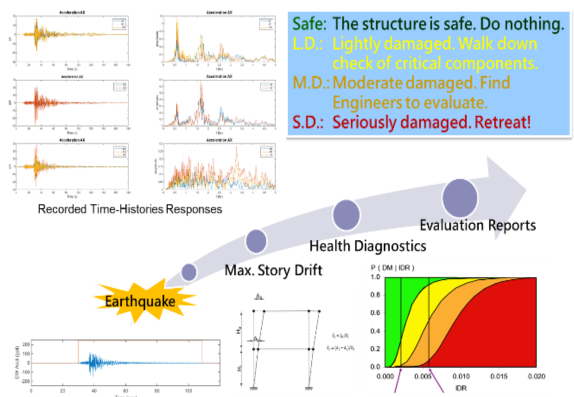

Figure 2. Monitoring earthquake response for structural health assessment processes

Structurally, the monitoring system comprises two primary components: hardware and software. The hardware typically consists of four integrated subsystems: (1) a sensor subsystem responsible for real-time data collection; (2) a data acquisition subsystem that converts analog sensor signals into digital formats; (3) a data communication and transmission subsystem facilitating reliable data transfer; and (4) a data analysis and processing subsystem responsible for preliminary data interpretation. These subsystems are interconnected via communication networks and managed by specialized system software to constitute a comprehensive monitoring infrastructure. Complementing the hardware, the software component incorporates sophisticated structural health diagnostics algorithms tailored to evaluate key physical parameters. These parameters commonly include structural natural frequency changes, modal damping variations, and inter-story drift measurements, thereby providing a rigorous and insightful assessment of structural integrity both during and following seismic events, as Figure 3 shows.

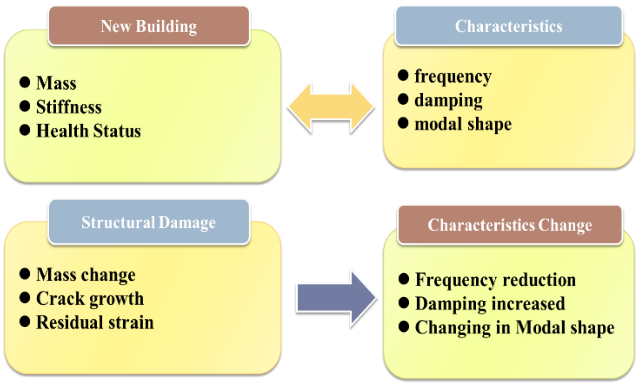

Figure 3. The characteristics of structures

3. STRUCTURAL HEALTH DIAGNOSTICS

Figure 4 presents the framework of intelligent structural monitoring. Since the Federal Emergency Management Agency [1] in the United States employs the Interstory Drift Ratio (IDR) as a rapid indicator for assessing earthquake-induced structural damage, this assessment is conducted by comparing measured IDR values to established thresholds specific to each structure. Following an earthquake, the recorded structural acceleration data is first adjusted to a zero-mean baseline. Subsequently, displacement signals are derived through double integration using the trapezoidal method. These displacement signals are then filtered utilizing a high-pass filter with a low cutoff frequency to mitigate baseline drift errors. The interstory drift obtained is normalized by dividing it by the corresponding floor height, and the maximum value obtained is multiplied by 100% to yield the maximum IDR for each floor. By referencing the Technical Manual of Earthquake Models for Multi-Hazard Loss Estimation Methods [2], structural types and elevation characteristics are categorized, facilitating the determination of specific damage thresholds for various damage states. Structural damage is classified into five levels: None, Slight, Moderate, Extensive, and Complete. For instance, the damage reference type designated as a high-rise concrete moment frame in regions with significant seismic risk has established IDR thresholds of 0.25%, 0.50%, 1.50%, and 4.00%, corresponding to incremental levels of damage severity.

4. SUMMARY AND CONCLUSIONS

In this paper, as Figure 5 shows, data from structural monitoring systems is transmitted and systematically stored in cloud-based databases. Integrated with the aforementioned diagnostic algorithms, this data supports timely structural health assessments and the generation of structural safety reports. Routine reporting includes automated monitoring summaries, health diagnostic outcomes, and analyses confirming the functional status of seismic instrumentation. Additionally, these reports present comprehensive evaluations detailing variations in structural stiffness and natural frequency parameters over time. For seismic events exceeding a magnitude of 5, a concise post-event analytical report is disseminated within seven days, highlighting notable changes in structural stiffness and frequency attributes, accompanied by an assessment of the building's structural integrity.

Figure 4. Intelligent structural monitoring framework

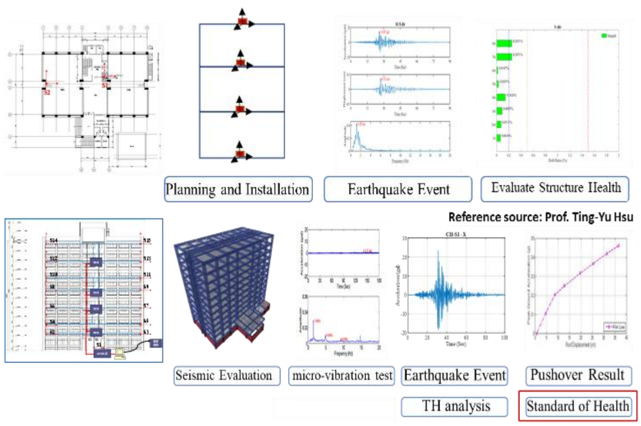

Figure 5. Structural damage assessment implications

5. REFERENCE

[1] Prestandard and Commentary for the Seismic Rehabilitation of Buildings. FEMA 356, November 2000.
[2] Hazus Earthquake Model. Technical Manual. Hazus 4.2 SP3. October 2020.