

# STRUCTURAL HEALTH MONITORING AND CONTROL RESEARCH IN NCREE

Chin-Hsiung Loh

*Department of Civil Engineering, National Taiwan University*

*e-mail: [loh0220@ccms.ntu.edu.tw](mailto:loh0220@ccms.ntu.edu.tw)*

## **Abstract**

The development, integration and development of knowledge and technology for health monitoring systems are essential for decisions pertaining to replacement and repair needs of constructed facilities. This paper describes the structural health monitoring and control researches in NCREE. Several methodologies for system identification and damage detection are developed and implemented in buildings and bridges to establish the knowledge-based seismic assessment data bank. To quantify the damage assessment through system identification a benchmark model will be developed and tested at shaking table. Methodologies on structural health monitoring will be verified through the test data. Structural control researches using this benchmark model will also be examined on the control effectiveness, particularly the application of MR dampers.

## **INTRODUCTION**

Throughout the world, strong motion instrumentation networks have been installed on buildings, bridges, dams and power plants. Recent strong motion earthquakes, Loma Prieta (1989), Lander(1992), Northridge (!994), Kobe (1995), Chi-Chi (1999) have yield a wealth of structural response data from instrumented structures. A particular emphasis shall be put on establishment of a strategy for instrumentation of structures and a methodology for utilization of the obtained results in mitigation of the existing seismic hazard related to certain structures. More specifically, a complete set of recordings has been obtained should provide useful information to: (i) check the appropriateness of the dynamic model in the elastic range, (ii) determine the importance of nonlinear behavior on the overall and local response of the structure, (iii) determine the effect of nonlinear behavior on the frequency and damping, (iv) correlate the damage with inelastic behavior. Besides, the immense number of structures which are in used today requires more attention in the fields of preservation and rehabilitation. The costs for these measures are increasing enormously. It is necessary to develop and enhance methods for a precise service life prediction of engineering structures by means of innovative monitoring methods. The aim of structural monitoring is to recognize negative deviation from planned properties of the structures resulting from build-in fault, systematic changes of damages, to control development and, if necessary, to renovation. The monitoring of structures done either from time to time advice in the selection of measurement parameters, measurement locations, and transducers. The diagnostic model serves for damage detection, damage localization, the study of damage causes, and for damage assessment. This paper describes the structural health monitoring methodologies that have been

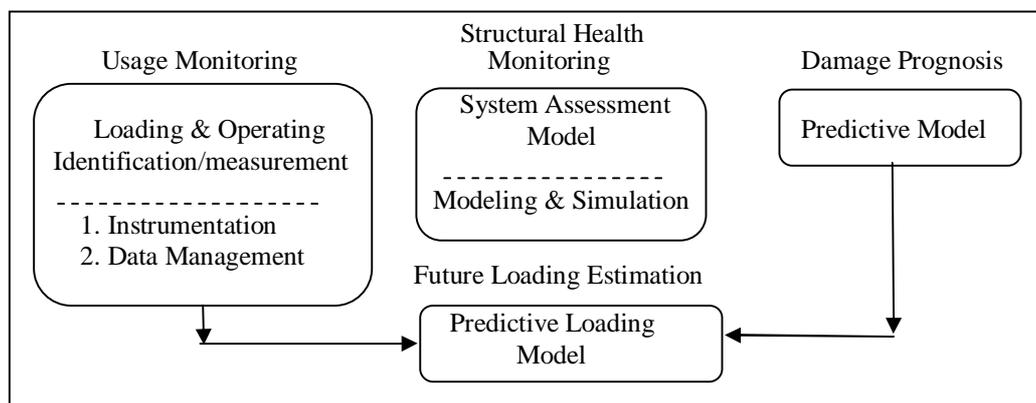
developed during the past few years at NCREE and NTU. Implementation of the methodologies to the seismic response data of buildings and bridges are introduced. As for the structural control research at NCREE, the semi-active control using MR damper is introduced. To quantify the effectiveness on the damage detection using system identification techniques as well as the control research a benchmark model will be developed.

## DEVELOP MODEL PARAMETER IDENTIFICATION MODULES

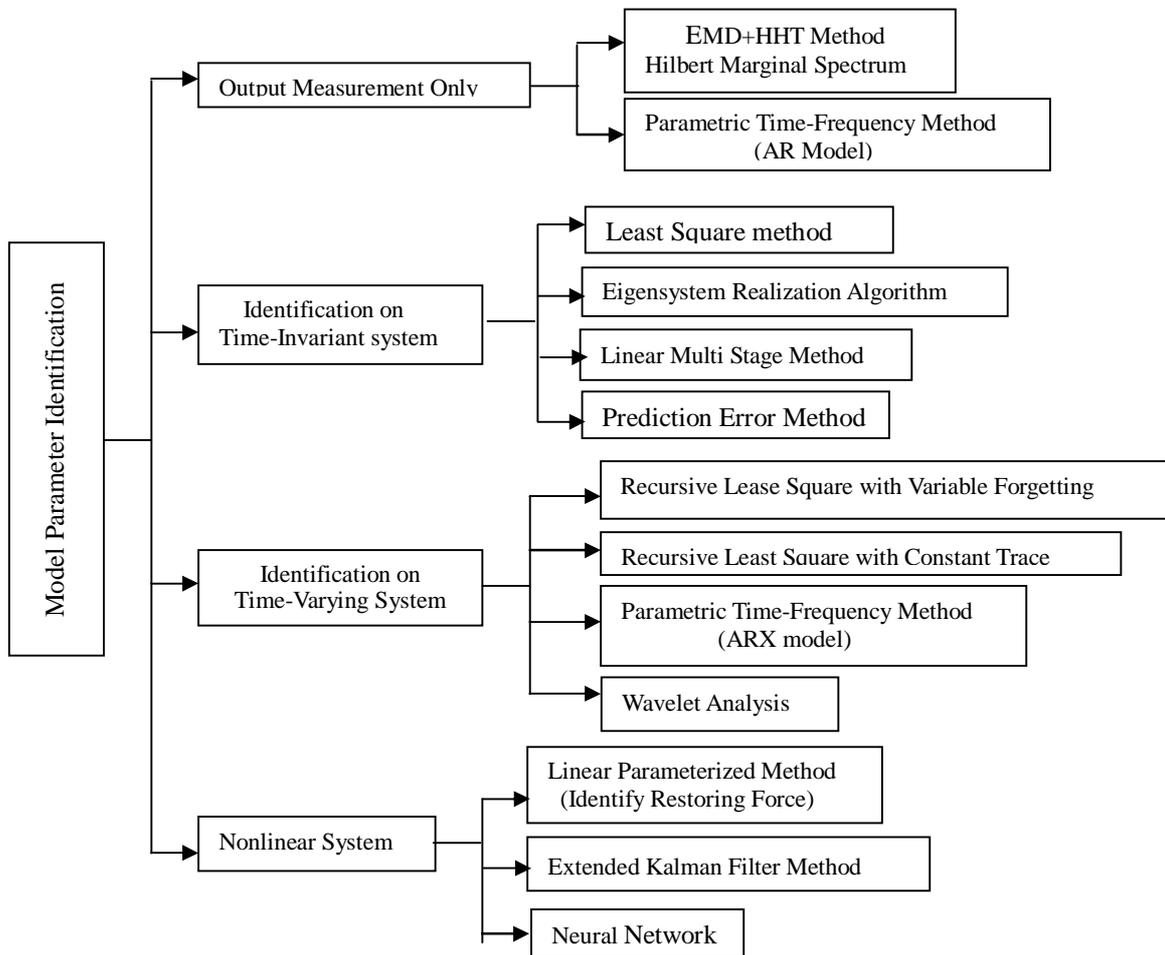
The design and implementation of the health monitoring systems necessitate the integration of (i) smart sensors, (ii) structural modeling, (iii) algorithms for detection of damages, (iv) on-line adjustment of current state condition. Figure 1 shows overall working frame on SHM. The goal of SHM will be the development of predictive model for damage prognosis and the predictive model of future loading and structural responses. The algorithms for detecting damages depend on using (i) output measurement only or (ii) both input and output measurement. Depends on linear time-invariant, or time-variant system, or nonlinear system, the identification algorithms are shown in Figure 2. Most of the methods have been implemented to identify the seismic response data of bridges and buildings under Taiwan Strong Motion Instrumentation Program (TSMIP). A knowledge-based seismic assessment which includes (i) observation of time-varying model parameters (such as including damping ration, natural frequency), (ii) quantification the contribution of nonlinear response from the result of identification, and (iii) perform damage assessment, are constructed. In relating to damage measure through SHM several indices are discussed: (1) change in flexibility and stiffness matrix, (2) change in mode shape or curvature, (c) change in resonance frequency and damping ratio.

To account for the wide scope of engineering structures, the future work will focus in the field of earthquake engineering hazard mitigation. This research is subdivided into the four research fields:

- a. Check and develop the efficiency of available monitoring techniques together with Information produced by simulation (including risk and weak-point oriented assessment methods),
- b. Develop damage characterization strategy (including stochastic state-space realization, extraction of flexibility proportional matrices from the realization results, localization and quantification of the damage),
- c. Develop criteria for evaluation and decision of planning, evaluation and iterative optimization of structural monitoring,
- d. Develop knowledge based system (modules of the expert system) for data acquisition and assessment in monitoring structures,



**Figure 1:** Framework of structural health monitoring



**Figure 2:** List of developed methodologies on model parameter identification.

## BENCHMARK MODEL FOR SHM

In order to verify the developed structural health monitoring & identification methodologies, a benchmark model will be constructed. As shown in Figure 3, two types of floor system will be constructed for the benchmark model: rigid floor and flexible floor. The first two model frequencies of the structural system are shown in Figure 4 for these two different floor systems. Through numerical simulation it is found that for ground motion excitation at  $PGA=500gal$ , in the case of rigid floor system, the first floor will have significant inelastic responses both in weak and strong axes. As for the case of flexible floor system when  $PGA=300gal$  the first floor will have significant inelastic responses both in weak and strong axes. Several research works can be studied through the test:

- (1) Overview of Local and Global health monitoring techniques, develop identification of input forces, develop new generation signal processing approach for structural health monitoring (such as vibration-based damage assessment module, on-line linear and non-linear damage detection techniques),
- (2) Establish model-aided monitoring and diagnosis and the model has to be adjusted on-line to the current state condition (adaptive model for SHM),
- (3) Development of structural monitoring strategies and procedures on a deterministic and probabilistic basis, measurement techniques, adaptive models which can adaptive themselves to a changing system, and the application to real structures.

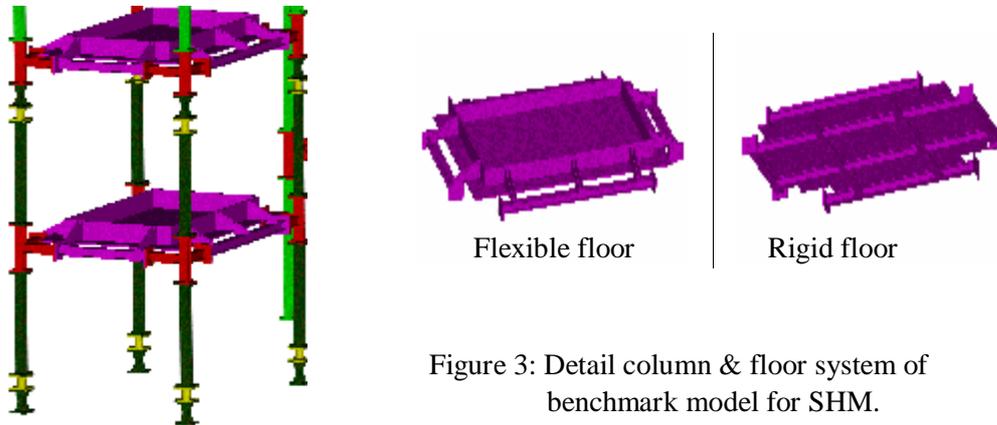


Figure 3: Detail column & floor system of benchmark model for SHM.

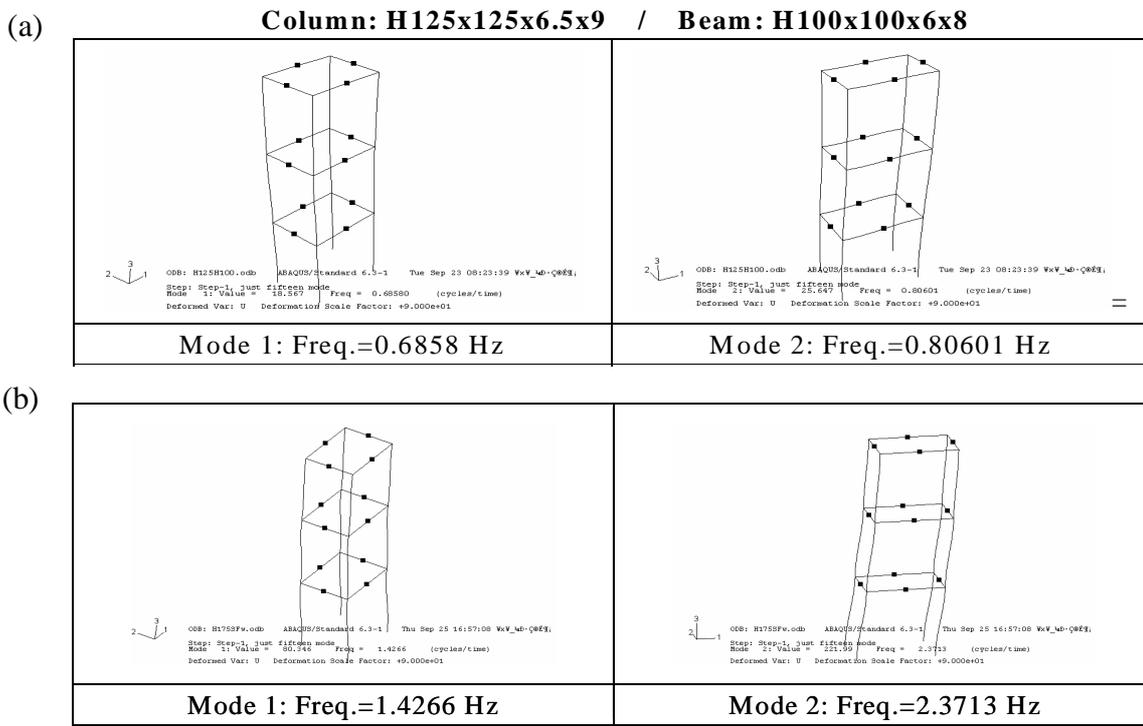


Figure 4: Identified first two modes of benchmark model; (a) Flexible floor, (b) Rigid floor.

## STRUCTURAL CONTROL RESEARCHES

One of the most important roles of structural control is to mitigate hazards due to disturbances induced by large earthquake or severe wind forces. For the past few years there has a rapid growth in the development of passive, active and semi-active control algorithms and devices. Several critical issues arise in structural control: (i) control effectiveness and costs among different control algorithms and devices, (ii) too many degrees of freedom in a real structural system with limited information available from the structural response measurement, (iii) reliability and fail-safe mechanism related issues. To clarify these issues a similar benchmark model will also be developed for structural control researches. Figure 5 shows the model structure (2m x 3m in plane and 3m for each story, 6.0 ton/per floor). From NCREE point of view semi-active control with MR dampers will be the focus of this control study. Lower power consumption, higher reliability and fail-safe mechanism make the semi-active control

technique one of the promising approaches for the seismic mitigation of civil engineering structures.

Magnetorheological (MR) damper is one of the prosperous semi-active control devices [P. Y. Lin, L. L. Chung, C. H. Loh, C. P. Cheng, P. N. Roschke and C. C. Chang (2002)]. MR damper resembles an ordinary linear viscous damper but the cylinder of the MR damper is filled with special fluid that contains very small polarizable particles. The fluid can be changed drastically from liquid to solid and vice versa by adjusting the magnitude of the magnetic field produced by the coil wrapping around the piston head of a MR damper. When no current supplied to the coil, a MR damper behaves as an ordinary viscous damper. On the other hand, when current is sent through the coil, the fluid inside a MR damper becomes semi-solid and its yield strength depends on the current applied. Since the control force is not applied directly to the structure but it is just to be utilized to adjust the parameters of a MR damper, the control instability never occurs and only small amount of energy is required. Therefore, MR damper is reliable and fail-safe.

Based on the developed MR-damper in NCREE several performance tests were conducted. The Bouc-Wen model was utilized to establish the numerical model of the MR device in order to simulate the control feasibility. Fuzzy Logic control algorithm was then utilized to determine the command voltage of the MR damper. Through numerical simulation of an isolated bridge, the effectiveness of the system controlled by MR dampers using the Fuzzy Logic control algorithm was investigated [Loh et al. 2003]. A full-scale building structure with only one story is also used to verify the control effect of this MR damper through shaking table test. The semi-active control system is design by “NEFCON”[Lin et al. 2002]. The “NEFCON” block is the main parts of the design of semi-active controller. In this block, control parameters in three parts have to be assumed. The first part is to define an error definition surface. The second part is to set the input limits and output gain (for example:  $1.5\text{m/s}^2$  and  $50\text{ m/s}^3$  for the acceleration and jerk inputs; 4volt for the output gain). The last part is the control parameters setting in the “learning algorithm” block. (for example: 11 and 8 membership functions for input and output; 2, 3, 4 cycles for phase 1, phase 2 and optimization; 0.04 for the learning rate ---- semi-active control/case 6). The future research on the application of semi-active control using MR damper will be the implementation of MR damper to raised floor in order to control the secondary structure for high-tech Fab.

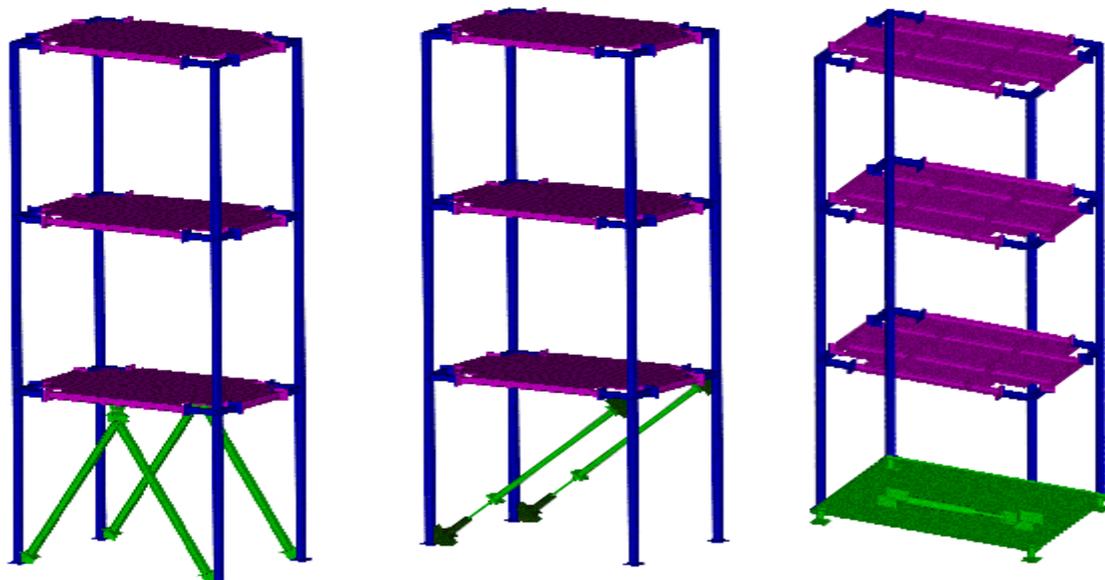


Figure 5: Benchmark model for structural control: bracing system & isolation system.

## CONCLUSIONS

It is worth to stress that the primary target of the structural health monitoring techniques is to provide a synthetic index of the structural state. A useful structural monitoring system should be able to discern critical event and perform a preliminary evaluation from the measures data. Through sensing system one can monitor the structure through its fabrication phase, provide in service monitoring of its state of health through to the end of its useful life. The smart structure can be developed. Besides, for the enhancement of performance of infrastructure, structural control needs to be implemented. **Figure 6** shows the confluence of sensing system, actuation system and neural network system to set the stage for a broad class of structure. Integrated researches can be conducted through such a framework.

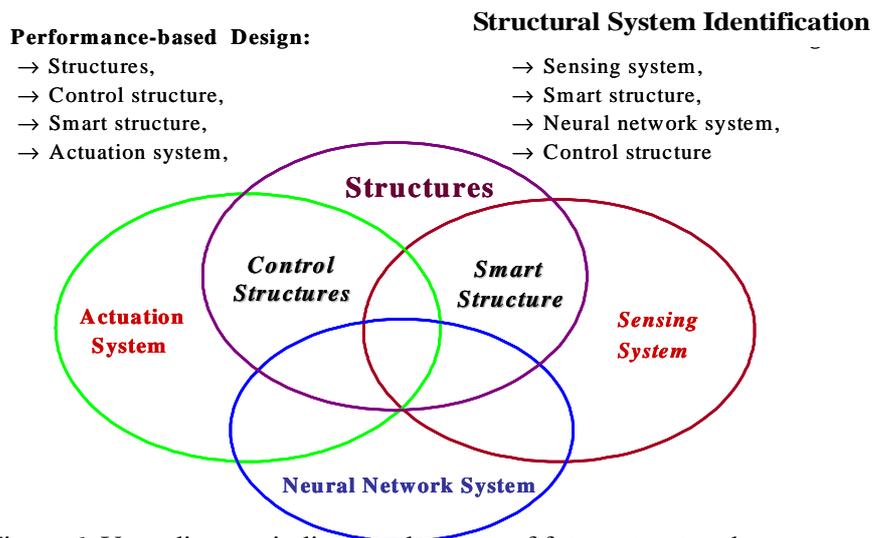


Figure 6: Vann diagram indicating the types of future structure by the confluence of different research field.

## REFERENCES

- Loh, C.H., C.C. Huang and C.Y. Lin, "Time Domain Identification of Frames under Earthquake Loading," *ASCE, J. of Engineering Mechanics*, Vol.126, No.7 July, 2000, 693-703.
- Z. K. Lee, T. S. Wu and C. H. Loh, "System Identification on Seismic Behavior of an Isolated Bridge", *J. of Earthquake Engineering and Structural Dynamics*, 32, 2003, 1797-1812.
- Loh, C. H., L. Y. Wu, and P. Y. Lin, "Displacement Control of Isolated Structure Using Semi-Active control Devices," *J. of Structural Control*, 10, 2003, 77-100.
- Lin, P. Y., L. L. Chung, C. H. Loh, C. P. Cheng, P. N. Roschke and C. C. Chang, "Experimental Study of Seismic Protection for Structures Using MR Dampers," 12<sup>th</sup> European Conference on Earthquake Engineering, Paper No. 259, London, 2002.
- Loh, C. H., "Structural Control Research in Taiwan," *Proceedings of the 3<sup>rd</sup> WCSC* (Editor: F. Casciati), Vol.1, Como, Italy, 2002, 115-124.