論文の内容の要旨

論文題目 System Identification of Structure and Soil-Structure Interaction with Limited Information
(制限された情報を用いた構造物及び地盤－構造物の相互作用のシステム同定)

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Existing structures suffer from an actual operating environment, excessive use, overloading, exposure to climatic variations and lack of sufficient maintenance and so on. In addition, structures can deteriorate due to the natural aging process or when subjected to unexpected loads, i.e. strong earthquake or high winds. The problem has added significance since the resources to build new structures are dwindling and the existing structures are aging; in some cases their design lives may have already been exhausted. Furthermore, there are many important structures in operation that were designed using provisions that are less rigorous than current practices, older structures whose properties may have changed over the years. Therefore, it is important to develop simple, inexpensive, and nondestructive evaluate procedures, which can be used routinely for the in-service condition assessment of existing and retrofitted structures.

This study is to develop the method to locate the damaged spots and to evaluate the damage. The proposed method is based on the fact that the values of structural parameters, in terms of mass, stiffness and damping characteristics change according to the shifts in the physical status of the structure. Details of these changes are reflected in changes of the structure properties. Thus, identification of structure parameters can be used to locate damaged spots and quantify the behavior of a structure.

A regular system identification procedure requires the measurement of input excitation forces and output responses. Unfortunately, the input excitation information is often difficult to obtain and hard to measure accurately. The system identification method not to require the input excitation information is needed, and the unknown input excitation could be of any type, including harmonic or random force of white noise.

Most system identification methods assume that the information of mass is known, Compared to the system parameters and the input load, mass is calculated relatively easily from the design references. However, there are live loads by the use of the structure as well as dead loads which is calculated from the design references in existing structures. If the use of the buildings or structures is changed or they are repaired, it is difficult to calculate the exact masses. Also sometimes, only part of a structure may have the mass information. It is needed to identify the system parameters (i.e. stiffness and damping) of the partial structure or the whole structure using only limited mass information of pre-selected locations.

The behavior of structure during an earthquake is greatly influenced by the property of the ground. The natural vibration characteristic of the ground may change the property of the earthquake. It increases or decreases the seismic load which excites the structure. If the deformation of the ground is occurred by the earthquake, rocking and sway may happen. And it may influence the behavior of the upper structure. The soil-structure interaction (i.e. rocking and sway) should be considered to apply to the existing structures affected by the earthquake.

When a structure suffers significant damage visible to the naked eye, there is an obvious problem. However and perhaps more seriously, the presence of defects after a natural disaster may not be obvious. Damages, especially by earthquake excitation, are occurred during an earthquake. The behavior of structure under strong earthquake excitation is easy to be nonlinear. Accordingly nonlinear system identification method is needed. Most nonlinear system identification methods in time domain should previously determine the hysteretic nature of the restoring force to identify the nonlinear behavior of structure (Yoshida, I. and Sata, T., 2004 & Lee, H. H. and Kim, S. S., 2002). In other words, they identify the coefficients for the decided hysteretic nature of the restoring force instead of identifying directly the unknown structural parameters. A system identification method of structural systems exhibiting inelastic restoring forces is needed to identify directly time-varying structural parameters and to estimate the restoring force-displacement relation successfully.

Including the proposed Advanced-ILS method, some system identification methods need data of displacement, velocity, and acceleration at each degree of freedom. Measuring the acceleration is relatively convenient and it does not need a set of fixed references. After measuring the acceleration response on the necessary point of structure, a digital method to double integrate accelerometer data in order to measure displacements is tried (Ribeiro et al, 1997). However, the acceleration data measured from the accelerometer during earthquake include the various noises. The velocity and displacement data calculated from the acceleration data including these noises may result in the distorted output different from the behavior of the real structure. Therefore, the procedure of eliminating noises using the efficient and proper process is important.

Considering the facts mentioned above, the primary objective of this study is to develop the system identification method to locate the damaged spots and to evaluate the damage in existing structures (buildings and similar structures that can be represented by a finite element algorithm) without disrupting their normal operations. To meet this primary objective, the proposed study aims to do the following:

1) to develop the system identification method to identify the structural parameters (i.e. stiffness and damping), where the input loading is not required to be measured and output response measurements are available at all degree of freedoms;
2) to develop the system identification method to identify the structural parameters of the partial structure or the whole structure using only limited mass information of pre-selected locations;
3) to develop the system identification method to consider the soil-structure interaction (i.e. rocking and sway) to apply to the existing structures affected by the earthquake;
4) to develop the system identification method to identify the time-varying structural parameters and to estimate the restoring force-displacement relation of the nonlinear structure;
5) to develop the procedure of eliminating noises from the measured acceleration data which are integrated to obtain the velocity and displacement data;
6) to verify the proposed system identification method by investigating numerical examples and shaking table tests.

This study includes eight chapters and an appendix. Chapter 1 is the introduction. It includes the statement of problem, the objection of research and the summary of chapter.

In Chapter 2, the literature review on system identification methods is given. The literature review includes the concept of system identification as well as currently available time domain system identification methods for the linear system and the nonlinear system.

Chapter 3 is about the proposed Advanced-ILS method which can identify element-level structural parameters (i.e. stiffness and damping) of a structure and a soil-structure interaction system using the structural responses at all degree of freedoms. It includes the structural model and the procedure of the proposed method. Then, the proposed method is applied to shear-type buildings. Five simulated numerical examples with different unknown input excitations including sinusoidal, random signal, and earthquake, are considered in this chapter. Both noise-free and noise-included responses are used in the identification processes of all numerical examples.

Chapter 4 is about the proposed Advanced-ILS method which can identify the system parameters of the partial structure or the whole structure using only limited mass information of pre-selected locations. It includes the partial structural model, substructure model, and the procedure of proposed method. Then, the proposed method is applied to shear-type buildings. Two numerical examples about the identification of the partial structure and two numerical examples about the identification of the whole structure are considered in this chapter. Both noise-free and noise-included responses are used in the identification processes of all numerical examples.

Chapter 5 is about the proposed Advanced-ILS method which can identify the time-varying system parameters and the restoring force-displacement relation of the nonlinear structure. It includes the nonlinear structural model of the proposed method. Then, the proposed method is applied to shear-type buildings. Three simulated numerical examples with different restoring force characteristics are considered in this chapter.

Chapter 6 is about the integral method of the measured acceleration data. It includes the error of measured acceleration data and the method (i.e. frequency domain filtering) to eliminate noises from the measured acceleration data which are integrated to obtain the velocity and displacement data. Two examples which use the measured acceleration data from the shaking table test are considered.

Chapter 7 is about the shaking table tests and the system identification using the measured acceleration data from the tests. 1×1span-three story shear-type structure is tested on the shaking table. Tests are two types. Test #1 is about the shear-type structure which is assumed that the base of structure is fixed. Four accelerometers are placed at each floor and shaking table with horizontal direction and three laser displacement sensors measure the horizontal displacement of each floor to compare with the integrated velocity and the double integrated displacement from the measured acceleration. Test #2 is about the shear-type structure which considers the soil-structure interaction. Two accelerometers and four laser displacement sensors are added at the base of structure with vertical direction. The measured acceleration data from the shaking table tests are integrated to obtain the velocity and displacement data after data processing which is explained in Chapter 6. These data are applied to the proposed Advanced-ILS method.

Chapter 8 is about the summary and conclusion of this study.