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Global and Local Approaches in Structural Identification

Méthodes globales et locales d'identification structurale

Globale und lokale Methoden für die Gebäudeaufnahme

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SUMMARY

Two approaches in structural identification using the Kalman filter algorithm for the purpose of damage detection and evaluation of the condition of structures are presented. These two approaches, which are the global and local identification, are first described and then their application to concrete structures is investigated. Vibration data for this study are obtained from shaking table tests conducted on a concrete space frame.

RÉSUMÉ

L'article présente deux méthodes d'identification structurale à l'aide de l'algorithme du filtre de Kalman ayant pour but la détection des dommages et l'évaluation de la condition des structures. Les deux méthodes d'identification globale et locale sont décrits, et leurs applications aux structures en béton sont étudiées. Les données sur les vibrations sont obtenues par des essais de cadres en béton sur des tables vibrantes.

ZUSAMMENFASSUNG

Vorgestellt werden zwei Methoden für die Gebäudeaufnahme, die den Kalmans Filteralgorithmus für die Schadenermittlung und Festsetzung des Bauzustandes verwenden. Diese zwei Methoden, die globale und die lokale Identifizierung, werden zuerst beschrieben. Anschliessend wird die Anwendung auf Betonkonstruktionen gezeigt. Zur Bestimmung von Schwingungsdaten wurden für diese Untersuchung Versuche an einem Betonrahmen auf einem Rütteltisch durchgeführt.

1. INTRODUCTION

Civil Engineering structures, after many years of service under severe environmental conditions, are damaged and their strength deter'orate. This is especially true for concrete structures which deteriorate due to various factors such as creep, shrinkage, steel corrosion, spalling of concrete, microcracks, etc. Since the primary concern of the civil engineer is to assure the safety of these damaged structures, the civil engineer must be concerned with the problem of evaluating the existing condition of structures. This is important in connection with damage assessment and rehabilitation of structures.

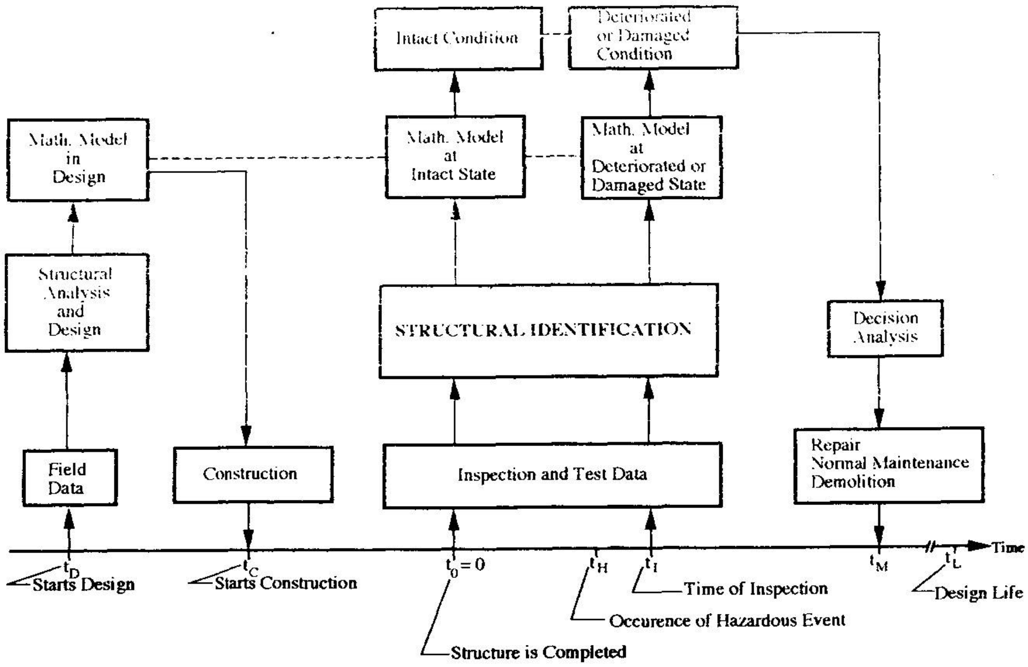

Fig. 1 Role of structural identification during the lifetime of a structure

Recently, with the development of new and sophisticated response measuring instruments and increase in computational capabilities, structural identification has started to be used as a means of evaluating the existing condition of structures. The role of structural identification during the lifetime of a structure can be understood clearly from Fig. 1. In designing structures, an integrated process is followed wherein field data, standard building codes and specifications, structural analysis and engineering experience are used to obtain the design of the structure with specified configuration, dimensions and material properties. The completed design of the structure, however, are based on an assumed mathematical model, the correctness of which have still to be verified. After completion of the structure at t_O and thereafter, structural identification can play an important role. At the completion of the structure, field testing and inspection can be conducted and the test data can be used in structural identification to perform the following objectives: (1) to verify the validity of the assumed mathematical model used in the design; and (2) to estimate the actual structural properties of the constructed structure and thus the mathematical model can be updated or improved. Results from this identification phase correspond to the condition of the structure at the intact state and can be used as a benchmark for comparison with the results obtained from future condition evaluation investigations. During its service life, especially when the structure is damaged due to an hazardous event such as a strong-motion earthquake, structural identification can again be carried-out to attain the following objectives: (1) to verify the validity of the existing mathematical model; (2) to identify changes in the structural properties of physical parameters governing the response of subassemblies, elements, connections and complete structure; and (3) to update or improve the model for a more realistic representation of the structure. Results from this phase of the investigation can be used in evaluating the soundness of the structure, observing the aging or deterioration of the structure and assessing the extent of damage caused by the hazardous event.

2. THE STRUCTURAL IDENTIFICATION PROBLEM

Structural identification consists of system identification techniques in which mathematical models for a structural system can be found by the use of a set of known inputs and corresponding outputs. Solution of a structural identification problem requires a state vector, X(t), which is governed by a mathematical model in the form of a differential equation

$$\frac{dX}{dt} = f[X(t), u(t), w(t), \theta(t), t] \qquad (1)$$

in which u(t) = input signal, w(t) = system noise and $\Theta(t)$ = unknown parameter vector. A noise corrupted version of the system state vector, Y(t) is observed and is related to the state vector by

$$Y(t) = h[X(t), u(t), w(t), \theta(t), t] \qquad (2)$$

where v(t) = observation noise. In structural dynamics, the order and form of the state equation is known and is derived from the equation of motion of an assumed mathematical model which can be a lumped mass or a finite element model. Hence, the identification problem reduces to estimation of structural parameters in the mathematical model. In this study, the extended Kalman filter with weighted global iteration (EK-WGI) developed by Hoshiya and Saito[1] was used in the identification.

3. GLOBAL AND LOCAL IDENTIFICATION

Based on the size of the structural system under consideration, structural identification can be classified into (1) global; and (2) local. Global identification models the complete structure in the deriving the state equation. The representation usually reduces to simple models such as lumped mass models especially when structures with many degrees-of-freedom (DOFs) are analyzed. Fig. 2(b) is which shows a spring-mass-dashpot model of a plane frame is an example of a global model. The simple modeling is necessary for an efficient and convergent identification. The models used by Hoshiya and Saito [1] are typical examples of global models in structural dynamics. The unknown parameters involved in global identification are those which affect the overall behavior of the complete structure such as frequency and damping or stiffness, **k**, and damping, **c**. In damage assessment of structures, global identification can show only that damage has occurred from the changes in the overall response and characteristics of the complete structure. It is difficult, however, to detect the cause of these changes in the behavior of the structure.

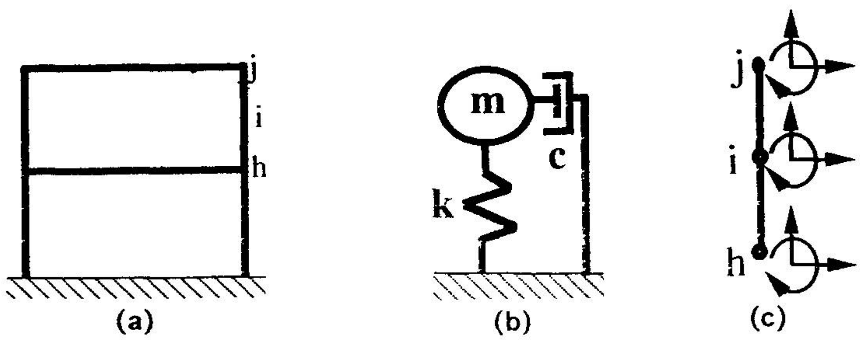

Fig. 2. (a) Plane frame; (b) Global model of plane frame; (c) Local model of frame member

Local identification is introduced as another approach in structural identification. In local identification, only a specific portion of the structure is modeled by substructuring methods. Unlike in global identification, more refined models such as finite element models can be used since the system under consideration is relatively small. Fig. 2(c) shows a model of a plane frame member with three DOFs per node. The unknown parameters involved in local identification are those which represent the structural properties of a substructure composed of an individual member or a system of members. By this approach, it is possible to detect the location and extent of damage in the structure through changes in the parameters of local portions of the structure such as an individual member. Oreta and Tanabe [2] developed a local identification method for framed structures such as plane frames and showed numerical studies to illustrate the identification of the stiffness properties of individual frame members.

As a practical and efficient identification method for damage detection and evaluation of structures, the two approaches can be adopted concurrently: (1) a simple model such as a lumped mass model can be used to represent the complete structure to detect the changes in the overall response; and (2) a refined model can be used to analyze a local and critical area to assess the degree of damage. These two approaches are adopted in the identification of a reinforced concrete space frame which was conducted by the authors.

4. EXPERIMENTAL INVESTIGATION

4.1 Description of Experiment

The test specimen is a reinforced concrete rigid space frame with a weight of 945 kg and height of 110 cm. The top slab is supported by four columns with 7.0 cm square cross-sections. At the midheight of the columns are stiffening beams with I-shape cross-sections. An additional steel mass weighing 935 kg was symmetrically installed at the top slab. The specimen was rigidly bolted on top of the shaking table. Fig. 3 shows you the plan and elevation of the specimen. The four columns are labeled as A, B, C and D.

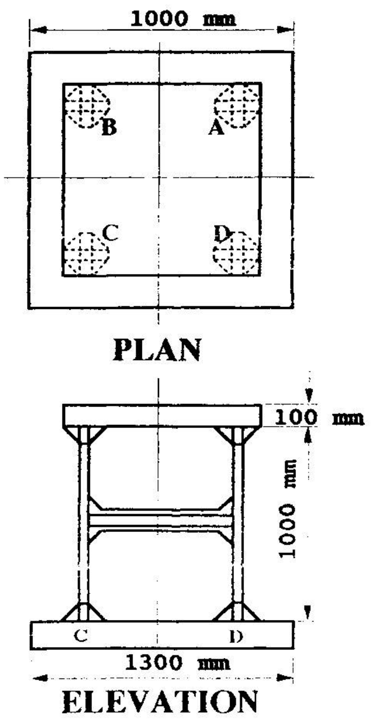

Fig. 3. Test specimen

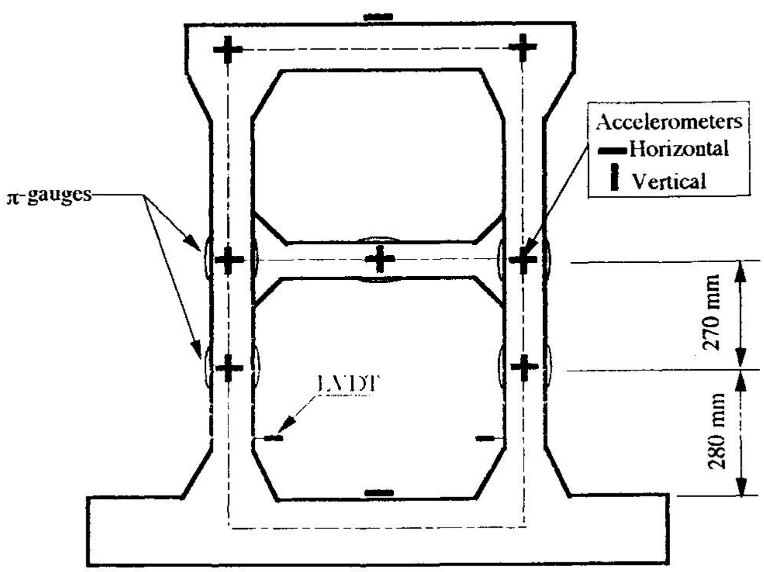

Fig. 4. Location of sensors

To systematically monitor the response of the structure, critical points of the members of the specimen were selected. At these points were installed different measuring devices or sensors. Strain-gauge type accelerometers were installed at the top and bottom slabs to measure the horizontal motion. At specified nodes of the column and beam members, vertical and horizontal accelerometers were fixed. Linear-variable displacement transducers (LVDT) were installed at the bottom ends of the columns. 100 mm pi-gauges (p-gauges) were fixed at opposite sides of the columns and beams at specified nodes. The locations of these sensors are shown in Fig. 4.

Free vibration tests were performed by hitting the top slab of the specimen by a hammer. This test was performed at the beginning before any shaking table test and after every one or two shaking table tests. The purpose of the free vibration test is to obtain acceleration data at the top slab for global identification of the dynamic properties of the complete structure.

Shaking table tests using a sinusoidal function as input excitation were performed. In the beginning, a forcing frequency of 7.0 Hz and an amplitude of 50 gal were used. To introduce gradual damage to the structure, the amplitude of the sine function was increased to 75, 100, 200, 300, 400 and 600 gal. The vibration data obtained from the different sensors located at the critical points of the specimen were used in the local identification of the stiffness properties of the frame members.

4.2 Global Identification

From the free vibration tests, the measured horizontal acceleration data of the top slab were used as observed data in the system identification by EK-WGI. The dynamic properties such as damping ratio and frequency of the structure which was modeled as a single-degree-of-freedom system were obtained at different stages. Fig. 5 presents the free vibration response of the top slab at the initial and failure stages. The decrease of the frequency from the initial condition to the failure condition is clearly demonstrated graphically and numerically as shown by the results from the identification in Table 1. Initially, the specimen had a frequency of about 6.7 Hz. At the early stages of shaking, the stiffening beams at midheight were damaged. With more intense shaking, cracks started to form in the columns and concrete cover started to spall. As a result, the stiffness of the complete structure decreased. At the failure condition, the frequency of the specimen was about 4.0 Hz which corresponds to more than 41% reduction with respect to the initial frequency.

Table 1. Results of Global Identification

	Damping (%)	Frequency (Hz)
Initial Condition	2.568	6.718
After 200 gal	2.565	6.231
After 400 gal	2.369	5.722
After 600 gal	2.796	5.083
Failure Condition	2.524	3.968

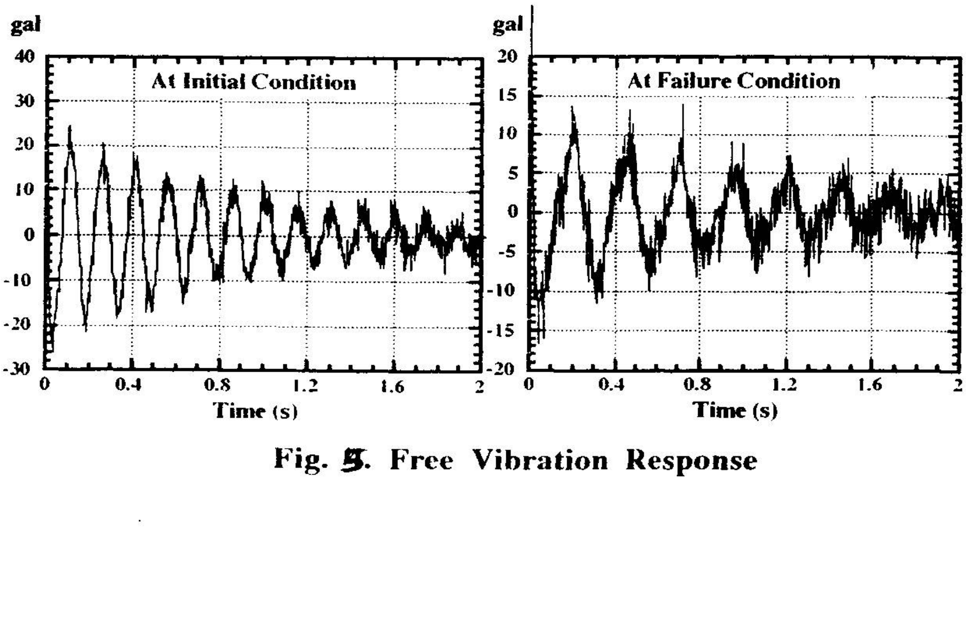

Fig. 5. Free Vibration Response

4.3 Local Identification

To identify the changes in the stiffness properties of the members of the specimen, the element identification method developed in Oreta and Tanabe [2] was adopted. In this method, the differential equation of motion was derived for each column by isolating the member from the structure. The responses at both ends and at the center were observed and used in the identification of the stiffness parameters of the columns. Four stages of the structure are considered. Initially, the response from a low amplitude shaking test of 20 gal was used to identify the stiffness properties at the initial condition. Then the vibration data from shaking table tests of amplitudes of 200 gal, 400 gal and 600 gal were used in estimating the effect of the damage in the stiffness properties of the columns. The results of the local identification of the flexural rigidities (EI), of the columns are shown in Table 2.

Table 2. Results of Local Identification of EI (x 10 ^10 N-cm^2)

	Column A	Column B	Column C	Column D
Initial:	7.901	8.500	8.432	8.000
At 200 gal	7.510	7.465	5.347	7.863
At 400 gal	7.500	7.235	5.166	7.669
At 600 gal	7.806	6.790	4.512	5.880

Tables 2 shows the decreasing value of the stiffness properties of the columns of the structure. Except for column A, the decreasing trend of the flexural rigidities of the columns was observed as follows: (1) Column B: 12.17% at 200 gal, 14.88% at 400 gal, and 20.11% at 600 gal; (2) Column C: 36.59% at 200 gal, 38.73% at 400 gal, and 46.99% at 600 gal; and (3) Column D: 1.71% at 200 gal, 4.13% at 400 gal and 26.5% at 600 gal. It is noted that column C has the largest flexural stiffness degradation followed by column D. This was also observed in the experiment where columns C and D were the worst damaged. The failure of these columns was characterized by spalling of concrete and vertical cracks due to bond failure.

5. CONCLUSION

The results of the study showed that the deterioration of the structure can be observed by system identification. Global identification showed the effect of damage to the dynamic properties of the structure. Frequency decreases with accumulation of damage. Local identification, on the other hand, illustrated the apparent reduction of the stiffness of the columns and indicated the columns which were severely damaged. In general, the identified structural parameters showed the deteriorating trend of the stiffness of the structure. This study must be extended to nonlinear behavior of structures since this behavior is what is usually experienced in severely damaged structures.

REFERENCES

1. HOSHIYA, M. and SAITO, E. "Structural Identification by Extended Kalman Filter," J. Eng. Mech. Div., ASCE, Vol. 110, No. 12, December 1984, pp. 1757-1770.

2. ORETA, A. and TANABE, T. "Element Identification of Member Properties of Framed Structures," J. Struct. Eng., ASCE, Vol. 120, No.7, July 1994, pp. 1961-1976.