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LOCALIZED IDENTIFICATION OF STRUCTURES BY KALMAN FILTER

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A method to estimate the structural parameters of a small section of a structure was presented. A structure was decomposed into two substructures which were attached at a common boundary and three subsystems resulted which were the primary, boundary and secondary systems. The identification of the structural parameters was concentrated on the secondary system. Incorporating the state and observation equations of the secondary system in the extended Kalman filter, the stiffness and damping parameters of the secondary system can be estimated. To illustrate the proposed localized identification approach, a shear building was analyzed and the identification was concentrated on the first story.

Keywords : *structural dynamics, system identification, Kalman filter, substructuring, primary-secondary system*

1. INTRODUCTION

Importance of system identification and parameter estimation in structural engineering has been recognized in recent years, particularly in the estimation of the existing condition and the degree of damage and deterioration of structures. For system identification purposes, structures are usually modelled discretely using simplified models such as lumped mass or finite element models. To represent reasonably the behavior of real structures, the discrete models usually involve many degrees of freedom (DOF) resulting in complicated and expensive (in terms of computation time) dynamic analysis especially when this is incorporated to a system identification and parameter estimation problem. For this reason, a research effort[1] was conducted to apply system identification and parameter estimation to a small section of the structure so as to reduce the size of the system under consideration. This attempt was further motivated by the fact that since damage of a structure is local and occurs at a critical section then it is only practical and reasonable to concentrate the analysis at a local and critical part of the structure. Hence, the term "localized identification" was derived.

As the initial step to carry out localized identification, the concept of primary-secondary system, which is basically a method of substructuring, was used to formulate the equations of motion necessary for system identification. In this approach, a structure was decomposed into two substructures which were attached at a common boundary and three subsystems were formed, i.e. primary, secondary and boundary systems. The identification was then concentrated on the smaller substructure which was the secondary system. Incidentally, the formulations resulted to a similar approach proposed recently in an independent study conducted by C. Koh et al[2] where the substructure approach is also used. Although the two formulations are generally similar, the present approach is more suited for structures represented by finite element models since the parameters that are being identified are the elements of the damping and stiffness matrices of the finite element model. Hence, the present formulation requires only one general computer program to analyze any finite element model. However, the disadvantage of this approach of identifying the elements of the damping and stiffness matrices is that there are more parameters to be identified.

In this paper, a procedure for localized identification of structural parameters was presented. The extended Kalman filter with weighted global iteration (EK-WGI) was proposed to be used in the estimation of the local structural parameters of a structure. Incorporating the state and observation equations formulated from the equation of motion of the small section of the structure in the Kalman filter algorithm, the stiffness and damping parameters were estimated. To illustrate the localized identification, a simple shear building model subjected to ground motion was analyzed and the identification was concentrated on the first story. Using the numerically simulated data of the shear building, the stiffness and damping parameters of the first story were reasonably estimated. The application to the shear building model is useful

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and practical especially for highrise buildings since the stuctural parameters of the first story, which is usually the most critical part of the building, can be estimated by knowing only the responses of the first and second stories.

2. EXTENDED KALMAN FILTER

As a background, the extended Kalman filter (EKF) will be described briefly. First, an appropriate set of state and observation equations derived from the equation of motion can be formulated and can be written generally as nonlinear equations respectively as :

$$\frac{dX}{dt}=f(X(t),t) \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

$$Y(k)=h(X(k),k)+v(k) \cdots\cdots\cdots\cdots (2)$$

where $X(k)$ is the state vector at time $t=k\Delta t$, $Y(k)$ is the observational vector at time $t=k\Delta t$, $v(k)$ is the observational noise vector with covariance matrix, $R(k)$ and Δt is the sampling time interval.

The EKF algorithm is a recursive procedure which starts from an assumption of the initial state vector, $\hat{X}(0/0)$ and its error covariance matrix, $P(0/0)$. The procedure[3),4)] which is given below is then performed recursively using one set of observations.

(1) Store the filter state : $\hat{X}(k/k)$ and $P(k/k)$

(2) Compute the predicted state :

$$\hat{X}(k+1/k)=\hat{X}(k/k)+\int_{k\Delta t}^{(k+1)\Delta t} f(\hat{X}(t/k),t)\,dt$$

(3) Compute the predicted error covariance matrix :

$$P(k+1/k)=\Phi(k+1/k)P(k/k)\Phi^T(k+1/k)$$

(4) Compute the Kalman gain matrix :

$$K(k+1)=P(k+1/k)M^T(k+1)[M(k+1) \times P(k+1/k)M^T(k+1)+R(k+1)]^{-1}$$

(5) Compute the filtered state by processing the observation, $Y(k+1)$:

$$\hat{X}(k+1/k+1)=\hat{X}(k+1/k)+K(k+1) \times [Y(k+1)-h(\hat{X}(k+1/k),k+1)]$$

(6) Compute the new (filtered) error covariance matrix :

$$P(k+1/k+1)=[I-K(k+1)M(k+1)] \times P(k+1/k)[I-K(k+1)M(k+1)]^T +K(k+1)R(k+1)K^T(k+1)$$

(7) set $k=k+1$ and return to step (1).

Here, $\Phi(k+1/k)$ is the state transition matrix which can be approximately obtained as

$$\Phi(k+1/k)\simeq I+\Delta t\left[\frac{\partial f_i(X(t),t)}{\partial X_j}\right]_{X(t)=\hat{X}(k/k)} \cdots\cdots\cdots\cdots (3)$$

for small Δt. I is a unit matrix. $K(k+1)$ is the Kalman gain matrix and $M(k)$ is the linearized coefficient matrix of the observation equation obtained as

$$M(k)=\left[\frac{\partial h_i(X(k),k)}{\partial X_j}\right]_{X(k)=\hat{X}(k/k-1)} \cdots\cdots (4)$$

For convergence purposes, the extended Kalman filter with weighted global iteration (EK-WGI) developed by Hoshiya and Saito[4)] can be applied. In this procedure, global iterations of the extended Kalman filter are carried out by overweighting the error covariance matrix at each global iteration. One global iteration means performing the EKF algorithm using one set of observations. At first, the filtering is performed for N observations with initial guesses of the state vector, $\hat{X}(0/0)$ and its error covariance matrix $P(0/0)$ to obtain the final values, $\hat{X}(N/N)$ and $P(N/N)$. Then, the second global iteration is performed using the final values of the parameters at the first global iteration as initial guesses. For the initial error covariance matrix, the diagonal elements of the covariance matrix at the first global iteration associated to the parameters are multiplied by a weight and used as initial values. This global iteration procedure is repeated until convergence in the system parameters is achieved, i.e., the initial and final values at a global iteration are almost the same.

3. EQUATION OF MOTION : PRIMARY-SECONDARY SYSTEMS

In substructuring, the complete structure is subdivided into several substructures. Without loss of generality, the structure can be divided into two substructures in which one of them is usually smaller (in mass and/or stiffness) compared to the other. The smaller substructure is commonly referred to as the secondary and the larger as the primary. These two substructures, which are attached at a common boundary or interface, are referred to as primary-secondary systems or simply P-S systems (**Fig.1**).

Let the vector X_p denote coordinates of degrees of freedom (DOFs) that belong only to the primary system, X_s denote solely the secondary DOFs and X_b denote DOFs of the boundary or interface points that belong to both the primary and secondary systems. The equation of motion of the composite P-S system in partition form can then be written as follows[5)] :

$$\begin{bmatrix} M_{pp} & 0 & 0 \\ 0 & M_{bb} & 0 \\ 0 & 0 & M_{ss} \end{bmatrix}\begin{Bmatrix} \ddot{X}_p \\ \ddot{X}_b \\ \ddot{X}_s \end{Bmatrix}+\begin{bmatrix} C_{pp} & C_{pb} & 0 \\ C_{bp} & C_{bb} & C_{bs} \\ 0 & C_{sb} & C_{ss} \end{bmatrix}\begin{Bmatrix} \dot{X}_p \\ \dot{X}_b \\ \dot{X}_s \end{Bmatrix}$$

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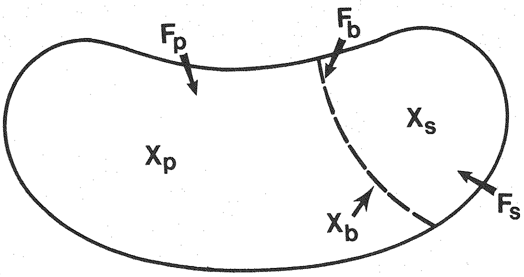

Fig.1 A Primary-Secondary System

$$+\begin{bmatrix} K_{pp} & K_{pb} & 0 \\ K_{bp} & K_{bb} & K_{bs} \\ 0 & K_{sb} & K_{ss} \end{bmatrix}\begin{Bmatrix} X_p \\ X_b \\ X_s \end{Bmatrix}=\begin{Bmatrix} F_p \\ F_b \\ F_s \end{Bmatrix} \cdots\cdots\cdots(5)$$

where (.) denotes time derivative, $\boldsymbol{M}, \boldsymbol{C}$, and $\boldsymbol{K}$ are the mass, damping and stiffness matrices, respectively and the subscripts p, s and b refer to primary, secondary and boundary DOFs, respectively. F_p, F_b and F_s are external forces applied to the primary, boundary and secondary DOFs, respectively. It has been assumed for simplicity that X_p and X_s are not inertially coupled with X_b. A lumped mass model satisfies this assumption.

The three parts of the composite P-S system when analyzed separately, can be represented by the three equations of motion corresponding to the primary, boundary and secondary systems, respectively, i.e.

$$M_{pp}\ddot{X}_p+C_{pp}\dot{X}_p+K_{pp}X_p=F_p-C_{pb}\dot{X}_b-K_{pb}X_b \cdots\cdots(6)$$

$$M_{bb}\ddot{X}_b+C_{bb}\dot{X}_b+K_{bb}X_b=F_b-C_{bp}\dot{X}_p-C_{bs}\dot{X}_s-K_{bp}X_p-K_{bs}X_s \cdots\cdots(7)$$

$$M_{ss}\ddot{X}_s+C_{ss}\dot{X}_s+K_{ss}X_s=F_s-C_{sb}\dot{X}_b-K_{sb}X_b \cdots\cdots(8)$$

4. STATE SPACE FORMULATION

Since our interest is on the identification of the structural parameters of a small and localized section of the structure, only the equation of motion of the secondary system will be considered, i.e.

$$M_{ss}\ddot{X}_s+C_{ss}\dot{X}_s+K_{ss}X_s=F_s-K_{sb}X_b-C_{sb}\dot{X}_b \cdots\cdots(9)$$

Sometimes this equation is simplified by neglecting the damping term on the righthandside. For structural systems, this damping term is usually small and its neglect causes insignificant error[6),7)].

The state equation can be derived from the equation of motion of the secondary system. Premultiplying Eq.(9) by M_{ss}^{-1} and introducing the following matrices

$$C_{ss}^*=M_{ss}^{-1}C_{ss},$$

$$K_{ss}^*=M_{ss}^{-1}K_{ss},$$

$$K_{sb}^*=M_{ss}^{-1}K_{sb},$$

$$C_{sb}^*=M_{ss}^{-1}C_{sb},$$

$$F_s^*=M_{ss}^{-1}F_s,$$

will result in

$$\ddot{X}+C_{ss}^*\dot{X}_s+K_{ss}^*X_s=F_s^*-K_{sb}^*X_b-C_{sb}^*\dot{X}_b \cdots(10)$$

The current identification problem consists of finding the optimal estimates of the unknown coefficients C^*_{ss}, K_{ss}^*, C_{sb}^*, and K_{sb}^*. The secondary mass matrix M_{ss} is assumed to be known for simplicity. Selecting X_s and $\dot{X}_s$ as the state variables and the coefficients of the matrices, C_{ss}^*, K_{ss}^*, K_{sb}^* and C_{sb}^* as augmented state variables, the state vector X becomes

$$X=[\,x_{s1}x_{s2}\cdots x_{sm}\dot{x}_{s1}\dot{x}_{s2}\cdots\dot{x}_{sm}c_{ss11}^*\cdots c_{ssmm}^*k_{ss11}^*\cdots k_{ssmm}^*k_{sb11}^*\cdots k_{sbml}^*c_{sb11}^*\cdots c_{sbml}^*]^T \cdots\cdots(11)$$

or it can be written in compact form as

$$X=[\,X_1^TX_2^TX_3^TX_4^TX_5^TX_6^T]^T \cdots\cdots(12)$$

in which

$$X_1=\{\,x_{s1}x_{s2}\cdots x_{sm}\}^T,$$

$$X_2=\{\,\dot{x}_{s1}\dot{x}_{s2}\cdots\dot{x}_{sm}\}^T,$$

$$X_3=\{\,c_{ss11}^*\cdots c_{ssmm}^*\}^T,$$

$$X_4=\{\,k_{ss11}^*\cdots k_{ssmm}^*\}^T,$$

$$X_5=\{\,k_{sb11}^*\cdots k_{sbml}^*\}^T,$$

$$X_6=\{\,c_{sb11}^*\cdots c_{sbml}^*\}^T,$$

where c_{ssij}^*, k_{ssij}^*, k_{sbij}^*, $c_{sbij}^*=ij$ elements of matrices C_{ss}^*, K_{ss}^*, K_{sb}^* and C_{sb}^*, respectively ; m=number of secondary DOFs and l= number of boundary DOFs. Eq.(11) or (12) is a $[2m+2m^2+2ml]$ dimensional state vector.

With the aid of Eq.(12), the differential equation (10) can be written into a state equation of the system as

$$\dot{X}=\begin{Bmatrix} \dot{X}_1 \\ \dot{X}_2 \\ \dot{X}_3 \\ \dot{X}_4 \\ \dot{X}_5 \\ \dot{X}_6 \end{Bmatrix}$$

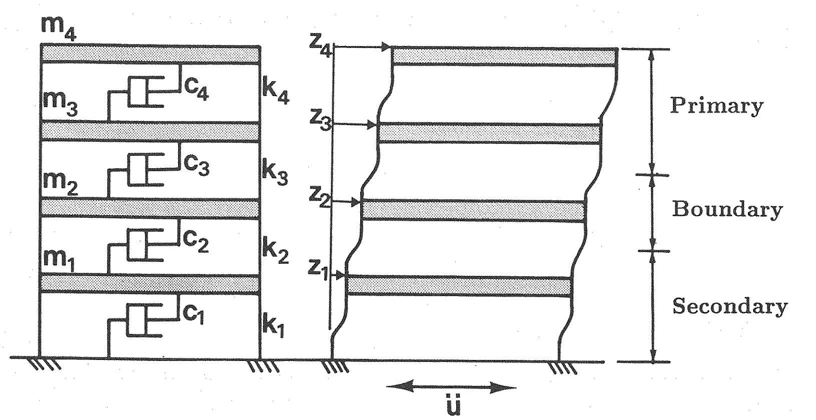

Fig.2 A four DOF shear building model considered as a composite P-S system

$$
=\left\{\begin{array}{c} X_2 \\ -C_{ss}^*(X_3)X_2-K_{ss}^*(X_4)X_1+F_s^*-K_{sb}^*(X_5)X_b-C_{sb}^*(X_6)\dot{X}_b \\ 0 \\ 0 \\ 0 \\ 0 \end{array}\right\} \quad \cdots\cdots (13)
$$

where matrices with (X_i) include elements in the vector X_i.

Eq.(13) is a continuous state equation of the dynamic system and corresponds to Eq.(1). Using an appropriate observation equation and response time histories of the secondary system, the structural parameters can be identified. Having identified the elements of the matrices C_{ss}^*, K_{ss}^* K_{sb}^* and C_{sb}^* and multipying by M_{ss}, an estimate of C_{ss}, K_{ss}, K_{sb} and C_{sb} can be obtained. It must be understood that inorder to implement the identification procedure described, the external force vector F_s, boundary displacement vector X_b and boundary velocity vector $\dot{X}_b$ must be known.

5. APPLICATION TO A SHEAR BUILDING

As a test problem of the localized identification of structures, a simple shear building will be analyzed. Consider the model of a four DOF shear building subjected to ground motion as shown in **Fig.2**.

The equation of motion for the shear building considered as a composite P-S system equivalent to Eq.(5) can be written as

$$
\begin{bmatrix} m_1 & 0 & 0 & 0 \\ 0 & m_2 & 0 & 0 \\ 0 & 0 & m_3 & 0 \\ 0 & 0 & 0 & m_4 \end{bmatrix}\begin{Bmatrix} \ddot{z}_1 \\ \ddot{z}_2 \\ \ddot{z}_3 \\ \ddot{z}_4 \end{Bmatrix}
+\begin{bmatrix} c_1+c_2 & -c_2 & 0 & 0 \\ -c_2 & c_2+c_3 & -c_3 & 0 \\ 0 & -c_3 & c_3+c_4 & -c_4 \\ 0 & 0 & -c_4 & c_4 \end{bmatrix}\begin{Bmatrix} \dot{z}_1 \\ \dot{z}_2 \\ \dot{z}_3 \\ \dot{z}_4 \end{Bmatrix}
+\begin{bmatrix} k_1+k_2 & -k_2 & 0 & 0 \\ -k_2 & k_2+k_3 & -k_3 & 0 \\ 0 & -k_3 & k_3+k_4 & -k_4 \\ 0 & 0 & -k_4 & k_4 \end{bmatrix}\begin{Bmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \end{Bmatrix}
=-\begin{Bmatrix} m_1 \\ m_2 \\ m_3 \\ m_4 \end{Bmatrix}\ddot{u} \quad \cdots\cdots (14)
$$

If we divide the composite system such that z_1 is the secondary DOF, z_2 is the boundary DOF and both z_3 and z_4 are the primary DOF, then the three equations of motion corresponding to the secondary, boundary and primary systems can be written as

$$
m_1\ddot{z}_1+(c_1+c_2)\dot{z}_1+(k_1+k_2)z_1 = -m_1\ddot{u}+k_2z_2+c_2\dot{z}_2 \quad \cdots\cdots (15)
$$

$$
m_2\ddot{z}_2+(c_2+c_3)\dot{z}_2+(k_2+k_3)z_2=-m_2\ddot{u}+k_2z_1 +[k_3\ 0]\begin{Bmatrix} z_3 \\ z_4 \end{Bmatrix}+c_2\dot{z}_1+[c_3\ 0]\begin{Bmatrix} \dot{z}_3 \\ \dot{z}_4 \end{Bmatrix} \quad \cdots (16)
$$

$$
\begin{bmatrix} m_3 & 0 \\ 0 & m_4 \end{bmatrix}\begin{Bmatrix} \ddot{z}_3 \\ \ddot{z}_4 \end{Bmatrix}+\begin{bmatrix} c_3+c_4 & -c_4 \\ -c_4 & c_4 \end{bmatrix}\begin{Bmatrix} \dot{z}_3 \\ \dot{z}_4 \end{Bmatrix}
+\begin{bmatrix} k_3+k_4 & -k_4 \\ -k_4 & k_4 \end{bmatrix}\begin{Bmatrix} z_3 \\ z_4 \end{Bmatrix}=-\begin{Bmatrix} m_3 \\ m_4 \end{Bmatrix}\ddot{u}
+\begin{Bmatrix} k_3 \\ 0 \end{Bmatrix}z_2+\begin{Bmatrix} c_3 \\ 0 \end{Bmatrix}\dot{z}_2 \quad \cdots\cdots (17)
$$

It would be practical to concentrate the identification on the first story which is usually a critical section for a building. Hence only Eq.(15) will be considered and it can be rewritten as

$$\ddot{z}_1+\left\{\frac{(c_1+c_2)}{m_1}\right\}\dot{z}_1+\left\{\frac{(k_1+k_2)}{m_1}\right\}z_1$$

$$=-\ddot{u}-\left\{\frac{k_2}{-m_1}\right\}z_2-\left\{-\frac{c_2}{m_1}\right\}\dot{z}_2 \cdots\cdots\cdots\cdots (18)$$

This equation corresponds to the general equation of motion of a secondary system derived as Eq.(10) given by

$$\ddot{X}_s+C_{ss}^*\dot{X}_s+K_{ss}^*X_s=F_s^*-K_{sb}^*X_b-C_{sb}^*\dot{X}_b \cdots (19)$$

in which $X_s=z_1$, $X_b=z_2$, $F_s^*=-\ddot{u}$, $C_{ss}^*=\{(c_1+c_2)/m_1)\}$, $K_{ss}^*=\{(k_1+k_2/m_1)\}$, $K_{sb}^*=\{-k_2/m_1\}$ and $C_{sb}^*=\{-c_2/m_1\}$. Having derived the equation of motion of the secondary system, the state vector given as Eq.(12) and the state equation given as Eq.(13) can be defined. In our present problem, the state vector consists only of 6 elements with $X_1=z_1$, $X_2=\dot{z}_1$, $X_3=C_{ss}^*$, $X_4=K_{ss}^*$, $X_5=K_{sb}^*$ and $X_6=C_{sb}^*$.

The observation equation (Eq.2) relating the observation to the state vector can now be derived. If the observed data are the displacements or velocities at the first story, the measurement or observation equation is given by Eqs.(20a) or (20b), respectively.

$$Y(k)=[1\ 0\ 0\ 0\ 0\ 0]X(k)+v(k) \cdots\cdots (20a)$$

$$Y(k)=[0\ 1\ 0\ 0\ 0\ 0]X(k)+v(k) \cdots\cdots (20b)$$

On the otherhand, if the observed data are the accelerations at the first story, the observation equation can be derived from the equation of motion as a nonlinear equation given by

$$Y(k)=F_s^*-C_{ss}^*\dot{X}_s-K_{ss}^*X_s-K_{sb}^*X_b$$

$$-C_{sb}^*\dot{X}_b+v(k) \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (20c)$$

and the linearized coefficient matrix can be derived from Eq.(4) as

$$M(k)=[-K_{ss}^*,\ -C_{ss}^*,\ -\dot{X}_s,\ -X_s,$$

$$-X_b,\ -\dot{X}_b] \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (21)$$

Although more complicated than the observation equation based on displacement or velocity and nonlinear in form, the observation equation based on acceleration is more useful in actual applications since acceleration records are more commonly available than other records. However, the effect of nonlinearity of the observation equation must be carefully investigated. The work of Denham and Pines[10] will be useful for this purpose.

Incorporating the state and observation equations in the EKF algorithm, the parameters can be identified. It is noted that the state variables X_3 to X_6 are the parameters to be identified. It must be understood that the input data which consist of the ground acceleration, $\ddot{u}$, boundary displacement, z_2, and boundary velocity, $\dot{z}_2$, must be known so that the identification can be implemented.

Table 1 Parameters of Structural Model (m_i : mass in kgf-sec²/cm, c_i : damping coefficient in kgf-sec/cm, k_i : story stiffness in kgf/cm)

Parameter	mass 1	mass 2	mass 3	mass 4
m_i	20	10	10	10
c_i	32	18	14	14
k_i	8000	4500	3500	3500

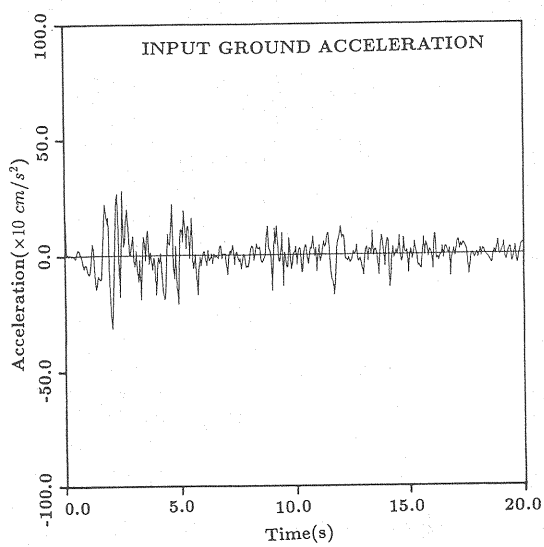

Fig.3 Input Ground Acceleration

6. NUMERICAL EXAMPLE

The identification method was applied to the four DOF shear building described in **Fig.2** using the structural parameters given in **Table 1**.

From **Table 1**, the parameters of the secondary system represented by the first story can be computed as $M_{ss}=20$, $C_{ss}=50$, $K_{ss}=12500$, $K_{sb}=-4500$ and $C_{sb}=-18$. Dividing each parameter by M_{ss} results in $C_{ss}^*=2.5$, $K_{ss}^*=625.0$, $K_{sb}^*=-225.0$ and $C_{sb}^*=-0.90$.

Using the linear acceleration method, Eq.(14) was solved to obtain the response of the composite system using a sampling time of 0.05 s with an earthquake acceleration data based on the El Centro (1940) acceleration as the input ground motion, $\ddot{u}$ (**Fig.3**). The calculated responses for m_1 and m_2 were used in the identification, where the calculated z_2 and $\dot{z}_2$ were used as input data (**Fig.4**), and the calculated responses of z_1, $\dot{z}_1$ or $\ddot{z}_1$ were used as the observed data (**Fig.5**)

In implementing the EK-WGI procedure, initial values for the displacement and velocity were set at 0. The initial error covariance matrix was set at 0.1 for response and 100 for unknown parameters. The

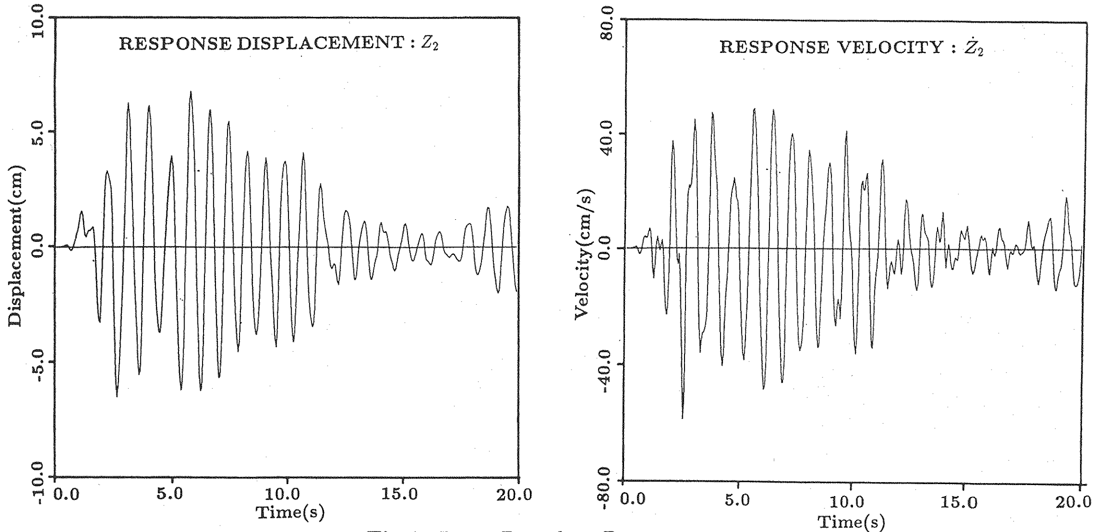

Fig.4 Input Boundary Responses

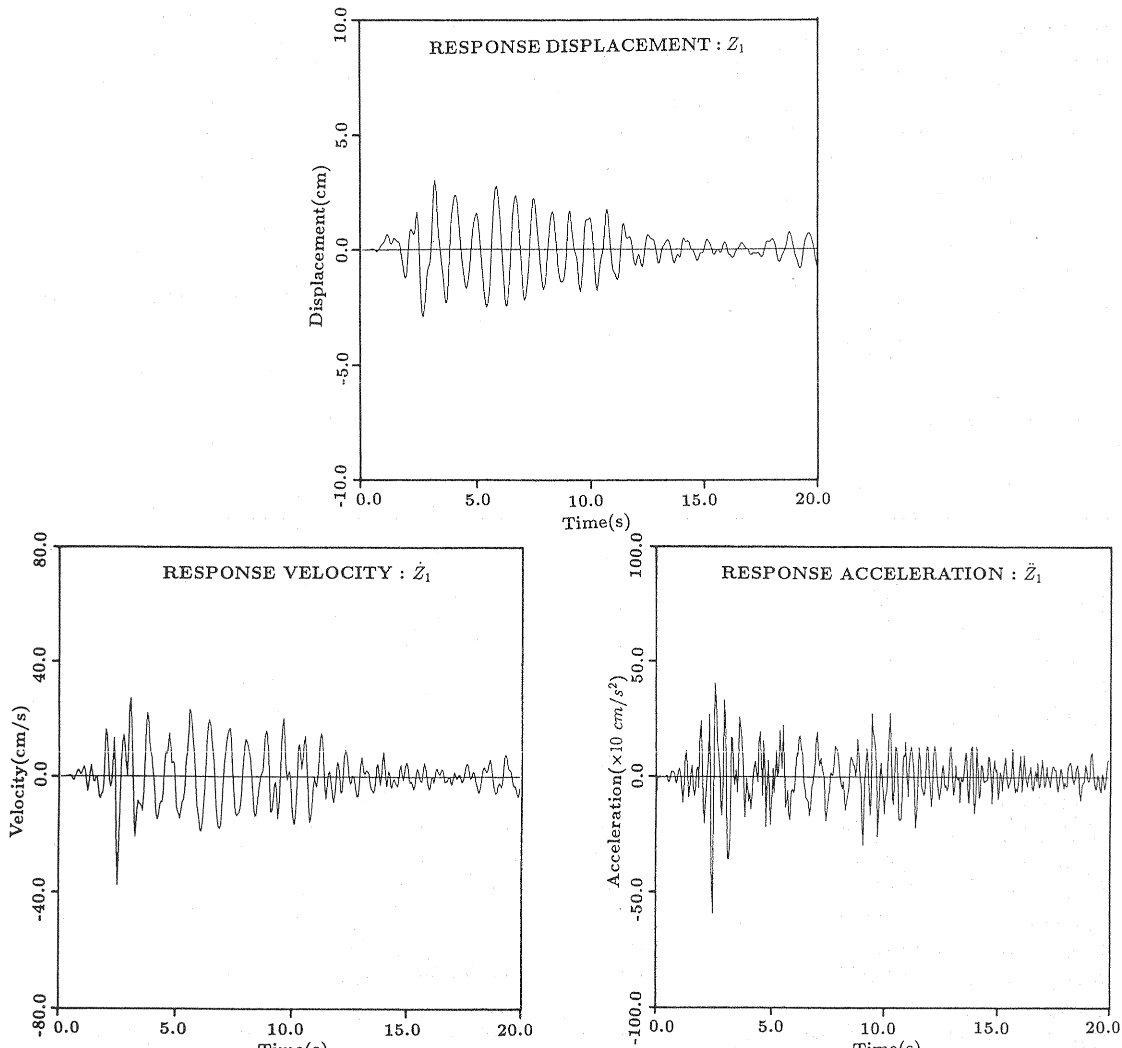

Fig.5 Observation Data

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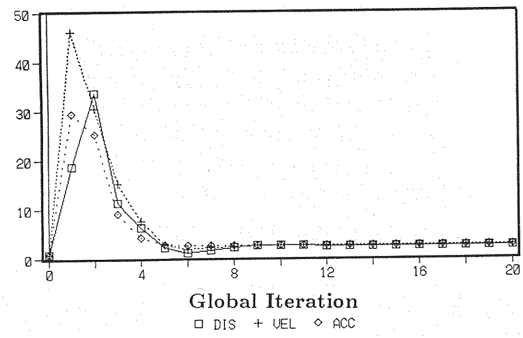
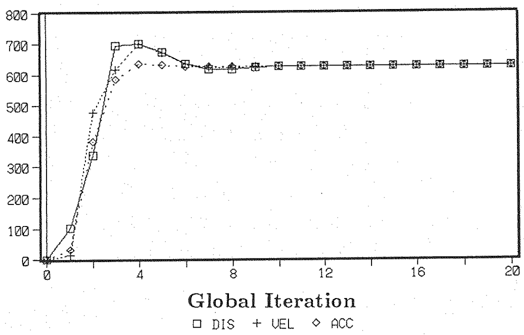
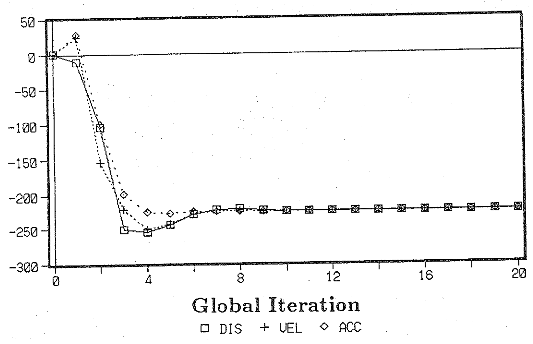


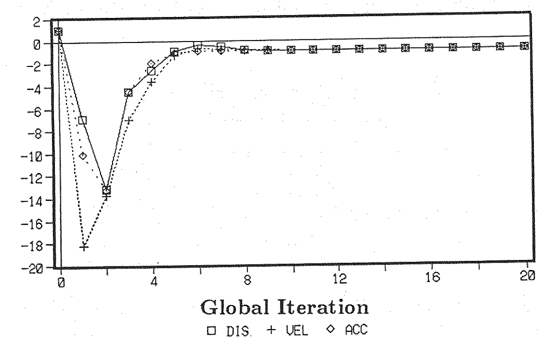
a) Parameter X_3 :$^{*}_{ss}$



b) Parameter X_4 : K^*_{ss}



c) Parameter X_5 : K^*_{sb}



d) Parameter X_6 : C^*_{sb}

Fig.6 Convergence of Parameters by EK-WGI

Table 2 Results of identification of parameters of secondary system

Parameter	True Value	Initial Value	Final Value		
			Disp.	Vel.	Acc.
C^*_{ss}	2.500	1.0	2.493	2.499	2.498
K^*_{ss}	625.0	1.0	625.0	625.0	624.9
K^*_{sb}	−225.0	1.0	−225.0	-225.0	−225.0
C^*_{sb}	−0.900	1.0	−0.897	-0.899	−0.898

Table 3 Estimated parameters of the shear building

Parameter	c_1	k_1	c_2	k_2
True Value	32.0	8000.0	18.0	4500.0
Estimated Value(Disp.)	31.92	8000.0	17.94	4500.0
Estimated Value(Vel.)	32.0	8000.0	17.98	4500.0
Estimated Value(Acc.)	32.0	7998.0	17.96	4500.0

noise covariance matrix for the observation response was taken as 1.0. A weighted value of 100 was used in the global iteration.

The displacement, velocity and acceleration time histories of m_1 were used as observed data. Assuming initial values of 1.0 for all the parameters, the EK-WGI procedure was carried out to estimate the parameters. Shown in **Table 2** are the results of the identification using the three different sets of observed data. **Fig.6** shows the convergence behavior of the parameters during identification using the EK-WGI algorithm. In general, the behavior of the parameters at the initial stage was unstable, but after several global iterations, the parameters started to converge to their final values. Using the three different sets of observed data, EK-WGI worked well in the estimation of the parameters even with poor initial guesses. It is interesting to note that the estimates obtained by using the acceleration as observed data were good despite the nonlinearity of the observation equation. This encouraging result, however, must be given further investigation for possible application to actual structures.

Multiplying the estimated parameters by $\boldsymbol{M}_{ss}$, we will obtain the estimates of $\boldsymbol{C}_{ss}$, $\boldsymbol{K}_{ss}$, $\boldsymbol{K}_{sb}$ and $\boldsymbol{C}_{sb}$. Using the relationship between the parameters of the secondary system and the actual stiffness and damping parameters of the shear building, the estimates of the first story parameters can be obtained as c_1 and k_1. Incidentally, the second story parameters, c_2 and k_2, were also estimated as shown in **Table 3**

From **Table 3**, we can see that the stiffness and damping parameters of the first and second stories of the shear building can be reasonably estimated. The estimates of the first and second story parameters were very close to the true values especially the stiffness parameters.

7. CONCLUSION

A procedure for localized identification of structural parameters using the extended Kalman filter was presented As a starting point, the concept of primary-secondary system, which is basically a method of substructuring, was applied. In the procedure, a structure was decomposed into two substructures which are attached at a common boundary and three systems, primary, boundary and secondary systems, were formed. The identification of parameters was concentrated on the secondary system. A structure, however, can be decomposed not only into two substructures but also into many substructures. The same localized identification procedure can be applied to estimate the parameters in these substructures by using the corresponding equation of motion of the substructure. With the localized identification procedure, the stiffness and damping parameters of selected substructures which are critical to the overall performance of the total structure can be estimated. However, the response at the boundary DOFs in the substructure must be available as input so that the identification can be implemented.

In the present localized identification formulation, the state equation necessary for system identification and parameter estimation was derived from the equation of motion of the secondary system. The elements of the damping and stiffness matrices of the equation of motion which are augmented to the state equation are the parameters to be identified. This approach, although it involves many parameters to identify, is easy to translate into a computer code and suited especially for finite element models.

As a test problem, the localized identification procedure was illustrated by analyzing a simple shear building where the first story parameters were reasonably estimated. Three different sets of observed data (displacement, velocity and acceleration) were used in the identification. The numerical results showed that the EK-WGI procedure worked well even with poor initial guesses of the parameters. Furthermore, the result obtained by using acceleration as observed data were encouraging as it is useful for identification of actual structures. The application to the shear building is useful and practical especially for highrise buildings since the structural parameters at the lower levels can be estimated without considering the response at the higher levels.

This study is only the initial step towards the objective of identifying the structural parameters of a local and critical part of a structure. To verify the capability and usefulness of the localized identification procedure, applications to more complicated structures must be conducted. After the numerical verification, the validity of the localized identification to actual applications must be tested by carrying out experiments using laboratory models and field experiments.

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