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IDENTIFICATION ON RESPONSE BEHAVIOR OF NEAR GROUND SURFACE DURING AN EARTHQUAKE

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SUMMARY

This paper presents an identification method on near ground surface behavior represented by a hysteretic restoring model, through the application of the Extended Kalman filter incorporated with a weighted global iteration. With this method, the restoring force characteristic of the ground can be identified by the nonlinear versatile model in terms of the model's parameters at the stage of their convergency to optimal ones. The convergency is attained in the global iteration of the Extended Kalman filter.

INTRODUCTION

An identification method to estimate parameters of a hysteretic restoring system was developed by appling the Extended Kalman filter incorporated with a weighted global iteration, shortly the EK-WGI method (Refs. 1,2,3). This paper makes investigation into an identification method on a hysteretic restoring force of a structural system by using the Bouc, Baber and Wen's versatile model (Refs. 5,6) and appling the EK-WGI method.

By the EK-WGI method, parameters of the model may be identified stably to optimal ones after the weighted global iterations of the Extended Kalman filter. For the numerical verification, a single degree of freedom hysteretic system was employed and the parameters were identified by using real earthquake data of a surface ground.

State Vector Equation for a Versatile Hystretic Model In order to apply the EK-WGI method to system identification problems, a set of a state vector equation and an observation equation must be properly formulated for the problem to be solved. The identification problem of estimating system model parameters may be incorporated within a state estimation problem by suitably augmenting the state vector with unknown parameters.

In the EK-WGI method, if the initial state vector X(to/to) and the initial error covariance matrix P(to/to) are given, then as the observation data Y(t) are processed, it is possible to estimate the state vector X(tk/tk) and the error covariance P(tk/tk) by the iterative calculation of the Extended Kalman filter on the set of a state vector equation and an observation equation.

For a stable estimation, the weighted global iteration of the algorithm is necessary. The detail of the EK-WGI method is given in the previous references (Refs. 1,2,3).

So, the present problem is the identification of a single degree of freedom hysteretic system with deterioration in strength and stiffness, and the model is represented according to Bouc, Baber and Wen as follows.

$$\ddot{u}(t)+2h_o\omega_o\dot{u}(t)+\omega_o^2\Phi(u(t))=-\ddot{f}(t) \tag{1}$$

$$\dot{\Phi}(u(t))=\frac{A(t)\dot{u}(t)-\nu(t)(\beta|\dot{u}(t)||\Phi(u(t))|^{n-1}\Phi(u(t))-\gamma\dot{u}(t)|\Phi(u(t))|^{n})}{\eta(t)} \tag{2}$$

where $\ddot{f}(t)$=input excitation, ho=fraction of critical viscous damping for small amplitudes, ω_o=undamped natural circular frequency of small amplitude response(=pre-yielding natural circular frequency).

Equation(2) represents a versatile hysteretic restoring force model which was first proposed by Bouc and later generalized by Wen. The versatile model can be applied to a large class of hysteretic systems (i.e.,inelastic, hysteretic and degrading behavior). In equation(2), the parameters β, γ, $A(t)$, $\nu(t)$, $\eta(t)$ and n control the hysteresis shape and degradation of the system.

The parameters $A(t)$, $\nu(t)$, and $\eta(t)$ are functions of the dissipated hysteretic energy, $\varepsilon(t)$, given by

$$\dot{\varepsilon}(t)=\omega_o^2\dot{u}(t)\Phi(u(t)) \tag{3}$$

Then $\varepsilon(t)$ may be obtained by integration, assumed that $\dot{u}(t)$ and $\Phi(u(t))$ are known. The parameters $A(t)$, $\nu(t)$ and $\eta(t)$ may then be written as

$$\left.\begin{array}{l} A(t)=1.0-\delta_A\varepsilon(t) \\ \nu(t)=1.0+\delta_\nu\varepsilon(t) \\ \eta(t)=1.0+\delta_\eta\varepsilon(t) \end{array}\right\} \tag{4}$$

where δ_A, δ_ν and δ_η are constants specified for the desired rate of degradation (Refs. 4,5).

Equations (1),(2),(3) and (4) are put into a state vector representation by introducing the state variables $X_1=u(t)$, $X_2(t)=\dot{u}(t)$, $X_3=\Phi(u(t))$, $X_4=\varepsilon(t)$, $X_5=ho$, $X_6=\omega o$, $X_7=\beta$, $X_8=\gamma$, $X_9=\delta_A$, $X_{10}=\delta_\nu$ and $X_{11}=\delta_\eta$:

$$\begin{bmatrix} \dot{X}_1 \\ \dot{X}_2 \\ \dot{X}_3 \\ \\ \dot{X}_4 \\ \dot{X}_5 \\ \dot{X}_6 \\ \dot{X}_7 \\ \dot{X}_8 \\ \dot{X}_9 \\ \dot{X}_{10} \\ \dot{X}_{11} \end{bmatrix} = \begin{bmatrix} X_2 \\ -2X_5X_6X_2-X_6^2X_3-\ddot{f}(t) \\ \dfrac{(1.0-X_9X_4)X_2-(1.0+X_{10}X_4)(X_7|X_2||X_3|^{n-1}X_3+X_8X_2|X_3|^{n})}{1.0+X_{11}X_4} \\ X_6^2X_3X_2 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \tag{5}$$

If observation data for the response displacement u(t) and the response velocity $\dot{u}(t)$ are available, the observation vector equation is given by

$$\begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} = \begin{bmatrix} 1,0,0,0,0,0,0,0,0,0,0 \\ 0,1,0,0,0,0,0,0,0,0,0 \end{bmatrix} \mathbf{X} + \mathbf{V} \tag{6}$$

where **V** is a noise vector of zero mean, white Gaussian process with the covariance, $E[\mathbf{V}(t_k)^* \mathbf{V}(t_j)] = \mathbf{R}(k)\delta_{kj}$, and δ_{kj} is the Kronecker delta.

It is noted that the state variables X_5 to X_{11} are the parameters to be identified in this study. Concerning the parameter n which appears in eq.(5), it is to be treated as a predetermined constant value (n=1) in order to avoid divergency during the EK-WGI processing.

Equations(5) and (6) are incorporated directly into the EK-WGI method for the parameter identification.

Identification of a Near Ground Surface Behavior The nonlinear behavior of a near ground surface was investigated using earthquake record. The records and the ground profile are shown in Figures 1 and 2. Based on that records, the relative responses at the surface are evaluated (by integrating them) and are given in Figure 3.

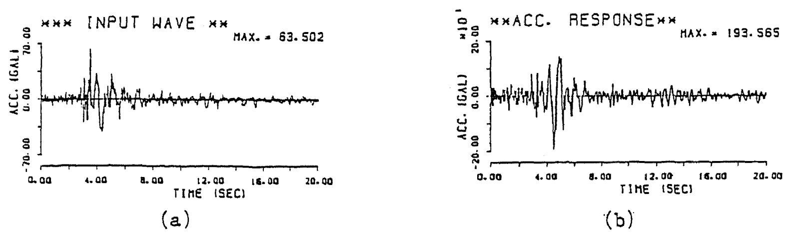
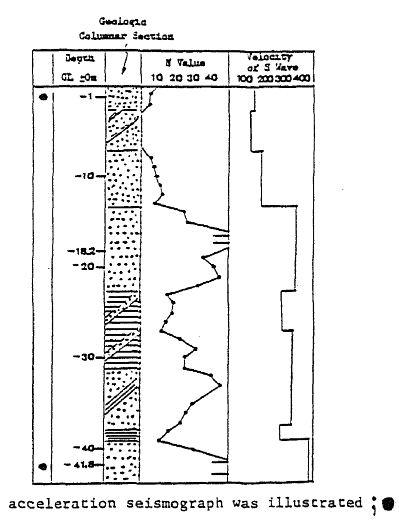


Figure 1. Base and Surface Ground Motions



acceleration seismograph was illustrated ; ●

Figure 2. Geological Profile

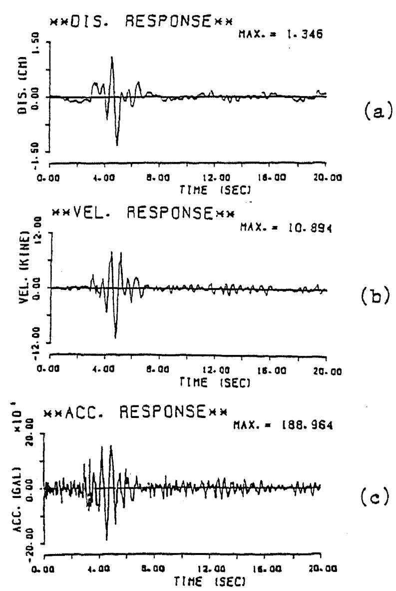


Figure 3. Response Time Hystories

The identification procedure was divided into two stages. At the first stage, the parameters ho and ωo were identified using the first portion of 3.5 sec duration of the observation data in Figure 3-(a),(b) and the input in Figure 1-(a) assuming that the responses were linear during the initial stage of oscillation.

In this portion of linear response, $X_7(=\beta)=0.0$, $X_8(=\gamma)=0.0$, $X_9(=\delta A)=0.0$, $X_{10}(=\delta\nu)=0.0$ and $X_{11}(=\delta\eta)=0.0$, the parameters X_5(ho) and X_6(=ωo) were identified. The initial conditions for this analysis are given in Table 1.

Table 1. Initial Conditions for Linear Model

Initial Conditions	X_1	X_2	X_3	X_4	X_5(=ho)	X_6(=ωo)
X(to/to)	0.0	0.0	0.0	0.0	0.01	15.0
P(to/to)	1.0	1.0	1.0	1.0	100.0	100.0
Note: Covariance of V=100.0						

The results are shown in Figure 4 where we find that the coefficient of viscous damping X_5(=ho) and the natural circular frequency X_6(=ωo) were stably estimated by the EK-WGI procedure. It was also found that the results were invariant as the number of the global iterations increased, where the weight of 100 was used in the global iterations.

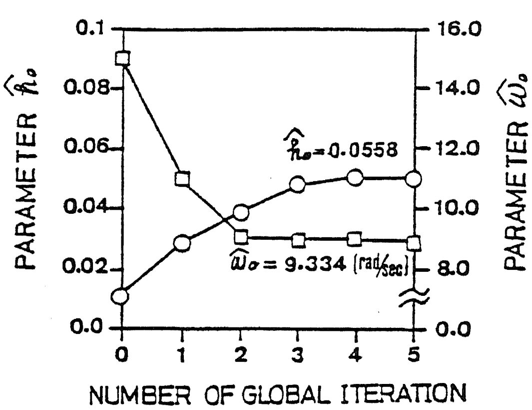


Figure 4. Convergency Process in Number of Iterations

For the second stage of identification procedure, the identified values at the first stage 0.0558 and 9.334 rad/sec respectively for X_5 and X_6 were fixed, and the parameters δ's, which denote degrading behavior, were assumed as $X_9(=\delta A)=0.0$, $X_{10}(=\delta\nu)=0.0$ and $X_{11}(=\delta\eta)=0.0$. This means that the deterioration of the stiffness and strength of the ground was presumedly small and was neglected in this example, and the parameters $X_7(=\beta)$ and $X_8(=\gamma)$ were identified. The initial conditions for this analysis are given in Table 2.

Table 2. Initial Conditions for Nondegrading Model

Initial Conditions	X_1	X_2	X_3	X_4	$X_5(=ho)$	$X_6(=\omega o)$	$X_7(=\beta)$	$X_8(=\gamma)$	$X_9(=\delta_A)$	$X_{10}(=\delta_\nu)$	$X_{11}(=\delta_\eta)$
$\hat{X}(to/to)$	0.0	0.0	0.0	0.0	0.0558	9.334	0.0	0.0	0.0	0.0	0.0
P(to/to)	1.0	1.0	1.0	1.0	0.0	0.0	5.0	5.0	0.0	0.0	0.0

Note: Covariance of V= 100.0 , ωo: rad/sec

Figures 5 show the result. In Figure 5, the first column shows the calculated hysteretic behaviors based on eq.(1); $\Phi(u(t))=(-\ddot{f}(t)-\ddot{u}(t)-2ho\omega o\dot{u}(t))/(\omega o^2)$ using observation data (Figure 3). The second and third columns show the corresponding estimated behaviors in the first iteration and the fifth iteration of the EK-WGI method respectively, where the parameter n of the versatile model was treated as a known value 1.0.

It is concluded from Figure 5 that the behavior of the ground was almost linear, since the restoring force-displacement curve was identified closely to a straight line passing through the coordinate origin.

It is also pointed out that the curve in Figure 5-(a) directly evaluted from the data does not represent the true hysteresis because of noise effect.

CONCLUDING REMARKS

An identification procedure was proposed for a hysteretic restoring system with deterioration both in strength and stiffness by using the Extended Kalman filter with weighted global iterations. The identification is based on a set of a properly formulated state vector equation and an observation vector equation which stem from the versatile hysteretic restoring model by Bouc and Wen.

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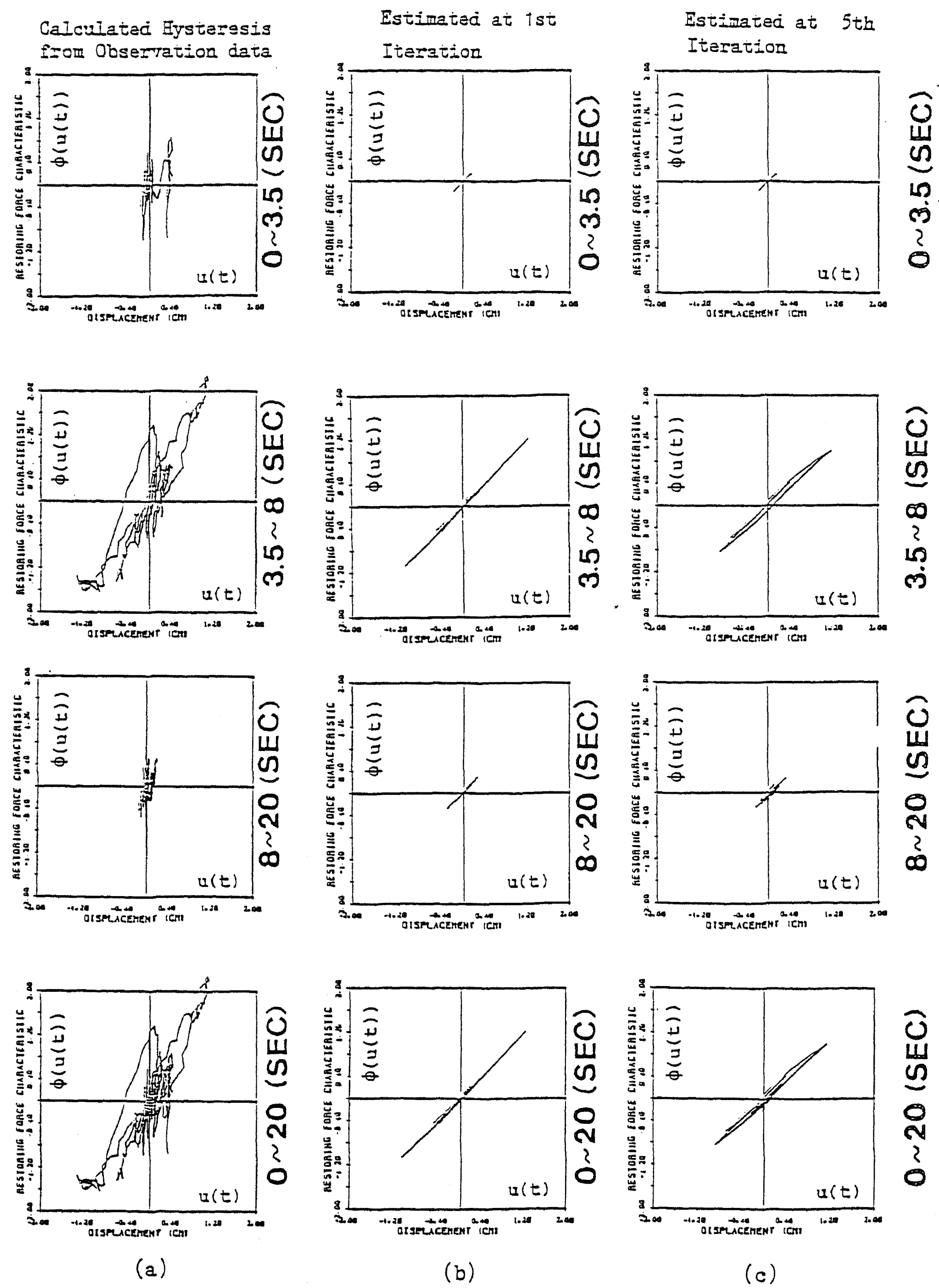

Figure 5. Estimated Hysteresis Restoring Force Characteristics