Neuronal Vibration Control of Conical Shell Structures with Active Dampers Subjected to Seismic Forces

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***Abstract*-There are some kinds of design methods against to seismic forces of buildings, i.e. aseismatic construction method, base isolation and vibration control. A shallow rotational shell is influenced the vertical direction of seismic motion greater than the horizontal one.**

A neuronal vibration control is applied to a shell structure with active dampers. The control object is a conical shell structure with active dampers, which work in the vertical direction at the anti-node of the first natural vibration mode. The purpose of control is the reduction of relative displacement to the ground at whole shell through adjusting damping ratio using neural network algorithm. An application method of neuronal vibration control of a shell structure has been considered furthermore. In this paper, it is considered that the differences of the rises of shell structures affect the results of neuronal vibration control.

I. INTRODUCTION

Vibrations of a shell or a building are occurred by wind forces, seismic forces and so on. It is important to attenuate stresses of a structure clearly. There are many studies of how to control the vibration of a building. In recently, base isolation or vibration control of the building is used as practically. Even if the shell structure is strong against the earthquake, the damage of the shell is not always nothing. Damages are concentrated mainly near supported parts. A neuronal vibration control of conical shell structures is carried out using the proposed method.

II. CONTROL OBJECT

The control object is the conical shell that is comprised of dampers, which work in the vertical direction at the anti-node of the first mode. The reason why shallow rotational shell structures are subjected to greater influence in the case of vertical motion than in the case of horizontal earthquake motion [1]. The shell structure is assumed to be input of the vertical component of seismic forces and is treated as an axisymmetrical problem. Neuronal vibration control simulation of three kinds of shells is carried out in this paper. The control object is shown in Figure 1 and the geometrical and material constants of the shells are shown in Table 1.

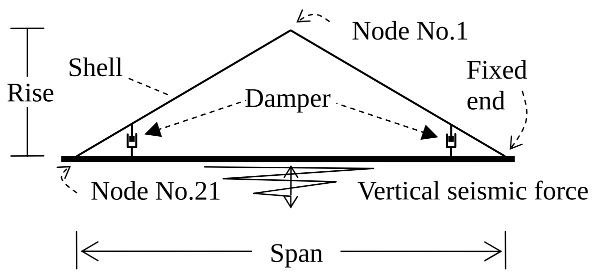

Figure 1 Control Object

Table 1 Geometrical and material constants of shell

Rise (3 kinds)	6m, 10m, 14m	Young's modulus	1.3524×10^{-3} (N/m^2)
Span	70m	Poisson's ratio	$\nu = 0$
Thickness	1m	Mass density	400(kg/m^3)

III. CONTROL METHOD

The three displacement components are hereby referred to the vertical and horizontal displacements and the angle of rotation on a nodal point of the discrete shell structure. It is equivalent to the relative vertical displacement complying with the ground obtained by the measurement unit attached to the said nodal point in the case of the real structure. The control target is settled to value of zero, which stems from the reason why the stress becomes smaller as the relative displacement is made smaller to avoid collapse of the structure. Let it be understood that the input values to the controller are the displacements, velocities, accelerations, seismic accelerations of the time delay, the output data of the hidden layer in the neural network and acceleration of seismic wave. The control signals, which are fed to a damper attached to the shell, help change the viscosity of the damper and the vibration control of the shell is accomplished. The controller is the Elman type neural network [2], and the learning regulations will be in accordance with the back-propagation using the relative displacement as a consequence of the control. The flow of vibration control is shown in Figure 2.

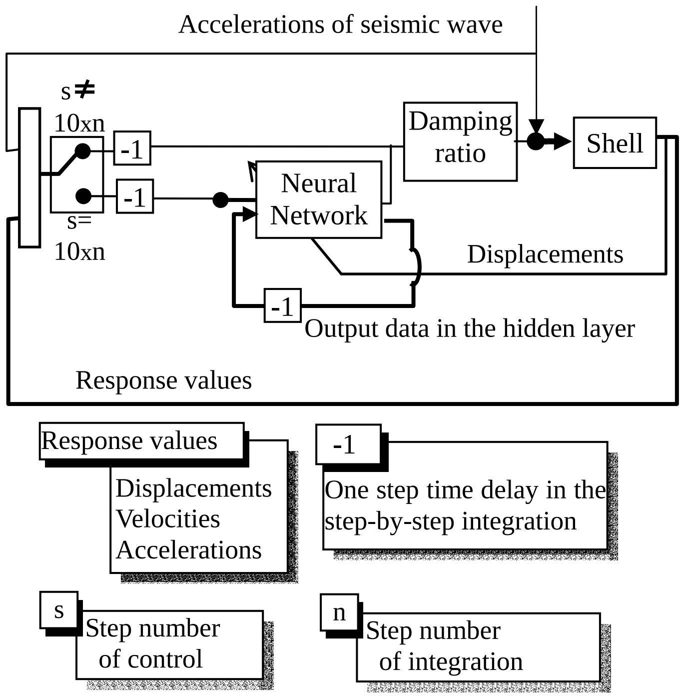

Figure 2 Flow of control

IV. NEURAL NETWORK

The controller utilized here is the Elman type neural network as mentioned above (see Figure 3). Each function at a unit in the hidden and the output layer is the sigmoid function.

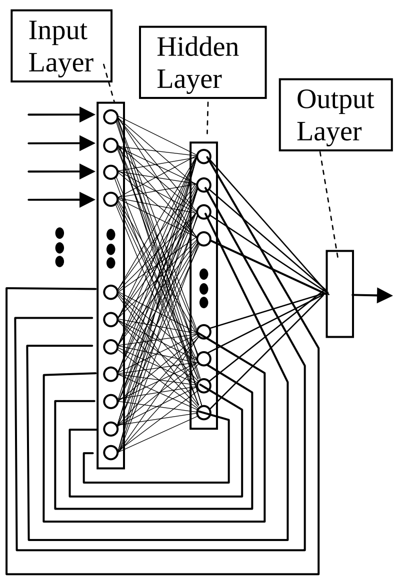

Figure3 Elman type network

The sigmoid function is as follows.

$$sigmoid(x) = \frac{1}{1 + \exp(-x)} \tag{1}$$

V. VIBRATION EQUATION OF SHELL

The finite element method with conical frustum elements is used to analyze the shell. The dynamic response of the shell is computed by the step-by-step integration method [3]. The vibration equation is as follows.

$$[M]\{\ddot{d}\} + [C]\{\dot{d}\} + [K]\{d\} = -f\{m\} \tag{2}$$

$[M],[K]$: Mass and stiffness matrix

(Mass matrix is used a lumped matrix.)

$\{\ddot{d}\} = \{\ddot{u}_1^*, \ddot{w}_1^*, \ddot{\chi}_1^*, \cdots, \ddot{u}_{20}^*, \ddot{w}_{20}^*, \ddot{\chi}_{20}^*\}$: Acceleration vector

$\{\dot{d}\} = \{\dot{u}_1^*, \dot{w}_1^*, \dot{\chi}_1^*, \cdots, \dot{u}_{20}^*, \dot{w}_{20}^*, \dot{\chi}_{20}^*\}$: Velocity vector

$\{d\} = \{u_1^*, w_1^*, \chi_1^*, \cdots, u_{20}^*, w_{20}^*, \chi_{20}^*\}$: Displacement vector

$u_i, w_i, \chi_i \ (i = 1, \cdots, 20)$:

Vertical and horizontal displacements, angle of rotation, respectively.

f : Acceleration of seismic force

$\{m\} = \{m_1, 0, 0, \cdots, m_{20}, 0, 0\}^T$: Mass vector

$i = 1, \cdots, 20$: Node number without supported end

The total element and node number are 20 and 21, respectively. The node numbers are 1 at the top, and 21 at the supported end. The damper is attached at the anti-node of the first mode. The control simulations are carried out about three kinds of rises of the shell; those are 6m, 10m and 14m. The node numbers of those and natural circular frequencies are shown in Table 2. A damping matrix and damping ratios are assumed as follows:

$$[C] = 2\omega_1 diag.(m_1\zeta_1, m_1\zeta_1, m_1\zeta_1, \cdots$$
$$, m_{node}\zeta_{node}, m_{node}\zeta_{node}(t), m_{node}\zeta_{node}, \cdots$$
$$, m_{20}\zeta_{20}, m_{20}\zeta_{20}, m_{20}\zeta_{20})$$

ω_1 : First natural circular frequency

$\zeta_{node}(t)$: Damping ratio at the anti-node of the first mode

Table 2 Node numbers and ω_1

Rise	6m	10m	14m
node	10	12	13
ω_1	16.268 (rad/sec)	23.698 (rad/sec)	30.052 (rad/sec)

VI. CONTROL SIMULATION

The control simulation is repeated in the following procedures from (B) to (F). Dynamic analysis of the shell is carried out at 0.002seconds interval, and the shell is controlled at 0.02 seconds interval.

(0) Initial states

- Displacements, velocities and accelerations are zero.
- Weights of network are initialized by random numbers in the interval from zero to one.
- All the damping ratios are 0.02.

• n=1; the first step of the step-by-step integration [3]

(A) Input earthquake and response analysis

The responses of shell by the earthquake at a step n+1 are analyzed used in the following equations (3), (4), (5).

$$\{d\}_{n+1} = \{E\}^{-1}\left([G]\{d\}_n + [V]\{v\}_n + [A]\{a\}_n + \beta h^2 \{F\}_{n+1}\right) \quad (3)$$

$$\{v\}_{n+1} = \frac{1}{\beta h^2}\left(\frac{h}{2}\{d\}_{n+1} - \frac{h}{2}\{d\}_n - \left(\frac{1}{2}-\beta\right)h^2\{v\}_n - \left(\frac{1}{4}-\beta\right)h^3\{a\}_n\right) \quad (4)$$

$$\{a\}_{n+1} = \frac{1}{\beta h^2}\left(\{d\}_{n+1} - \{d\}_n - h\{v\}_n - \left(\frac{1}{2}-\beta\right)h^2\{a\}_n\right) \quad (5)$$

where,

$\{d\},\{v\},\{a\}$:

Displacement, velocity, acceleration, respectively

$$[E] = [M] + \frac{h}{2}[C]_{n+1} + \beta h^2 [K]$$

$$[A] = \left(\frac{1}{2}-\beta\right)h^2[M] + \left(\frac{1}{4}-\beta\right)h^3[C]_{n+1}$$

$$[V] = h[M] + \left(\frac{1}{2}-\beta\right)h^2[C]_{n+1}$$

$$[G] = [M] + \frac{h}{2}[C]_{n+1}$$

$\beta = \frac{1}{4}$: Acceleration coefficient

$h = 0.002$: Small time interval (second)

(B) Calculations of neural network

The output of the neural network is calculated in the following equations when the integration steps is s=10 x n.

i) Output value in the hidden layer

$$y_{j,s} = sigmoid\left(\sum_{j=1}^{362} w_{jk}^{(1)} x_k - \theta_j\right) \quad (6)$$

$$(j = 1, \cdots, 181)$$

$w_{jk}^{(1)}$: Weight of connection between the hidden and the input layer

θ_j : Threshold of the unit in the hidden layer

$\{x\} = \left\{\{d\}_{n+1}, \{\dot{d}\}_{n+1}, \{\ddot{d}\}_{n+1}, \{y_{j,s-1}\}, f_n, f_{n+1}\right\}$:

Input data in the input layer

f_n : Acceleration of seismic force at step n

$y_{j,s}$: Output value at step s

ii) Output value in the output layer

$$o = sigmoid\left(\sum_{j=1}^{181} w_j^{(2)} y_{j,s} - \phi\right) \quad (7)$$

$w_j^{(2)}$: Weight of connection between the output and the hidden layer

ϕ : Threshold of the unit in the output layer

(C) Prediction value of the damping ratio

The damping ratio is predicted at a step n+2 in the following equation.

$$\zeta_{n+1} = 0.2 - 0.18o \quad (8)$$

(D) Input earthquake and response analysis

The response analysis is in the same (1) at a step n+2.

(E) Learning

The learning calculations and weights updating procedure are carried out in the following equations.

$$\delta E = \eta D \quad (9)$$

D : Maximum displacement

$\eta = 0.0021$: Learning rate

$$\delta w_i^{(2)} = \delta E \cdot (1-o) \cdot o \cdot y_{i,s} \quad (10)$$

$$\delta \phi = \delta E \cdot (1-o) \cdot o \quad (11)$$

$$\delta w_{jk}^{(1)} = \delta E \cdot (1-o) \cdot o \cdot w_j^{(2)} \cdot (1 - y_{j,s}) \cdot y_{j,s} \cdot x_k \quad (12)$$

$$\delta \theta_j = \delta E \cdot (1-o) \cdot o \cdot w_j^{(2)} \cdot (1 - y_{j,s}) \cdot y_{j,s} \quad (13)$$

$$w_i^{(2)} \leftarrow w_i^{(2)} + \delta w_i^{(2)} \quad (14)$$

$$\phi \leftarrow \phi + \delta \phi \quad (15)$$

$$w_{jk}^{(1)} \leftarrow w_{jk}^{(1)} + \delta w_{jk}^{(1)} \quad (16)$$

$$\theta_j \leftarrow \theta_j + \delta \theta_j \quad (17)$$

(F) Update step number

The step number n is updated in the following.

$$n \leftarrow n + 1$$

VII. SIMULATION RESULTS

Figure 4 shows Miyagiken-oki earthquake used for input acceleration is enlarged to 2m/sec^2. The control effects are estimated by comparison with non-control results. These results are shown in Figures 5-10. The meanings of NON and CONT are damping ratio fixed 0.02 and controlled one, respectively.

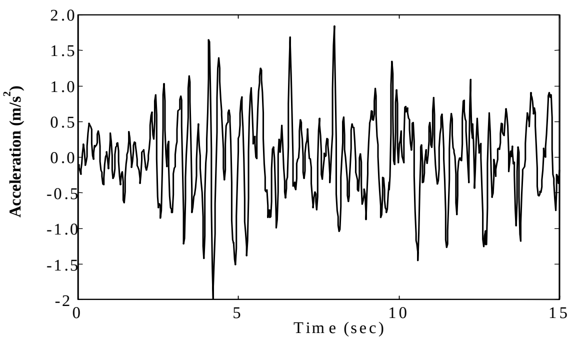

Figure 4 Miyagiken-oki earthquake (UD), June 12, 1978

A. Maximum displacements in the vertical direction

The maximum displacements in the vertical direction are shown in the Figures 5, 6 and 7, respectively.

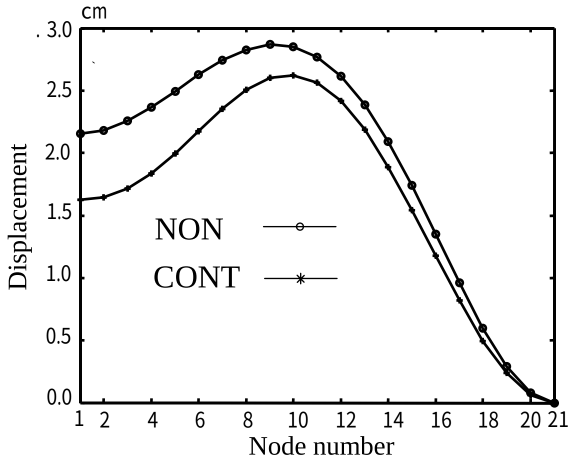

Figure 5 Vertical displacements (Rise 6 m)

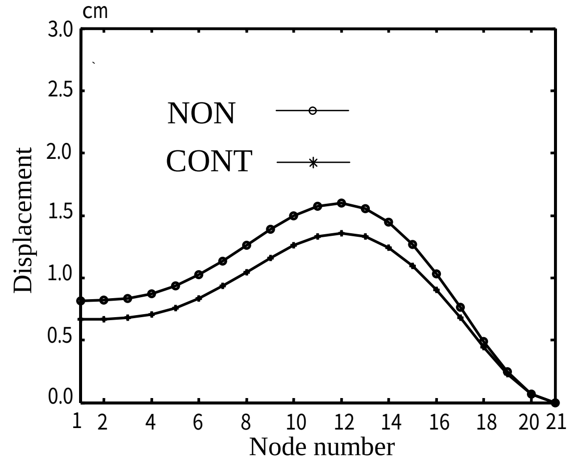

Figure 6 Vertical displacements (Rise 10m)

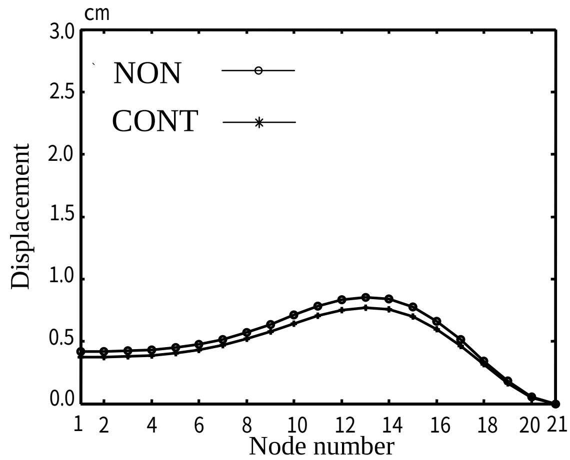

Figure 7 Vertical displacements (Rise 14m)

B. Maximum displacements in the horizontal direction

The maximum displacements in the horizontal direction are shown in the Figures 8, 9 and 10, respectively.

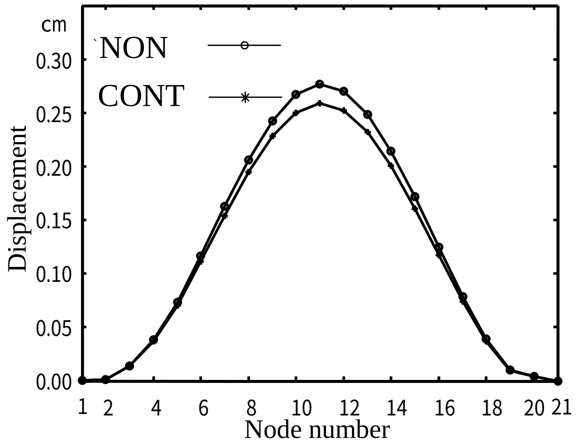

Figure 8 Horizontal displacements (Rise 6 m)

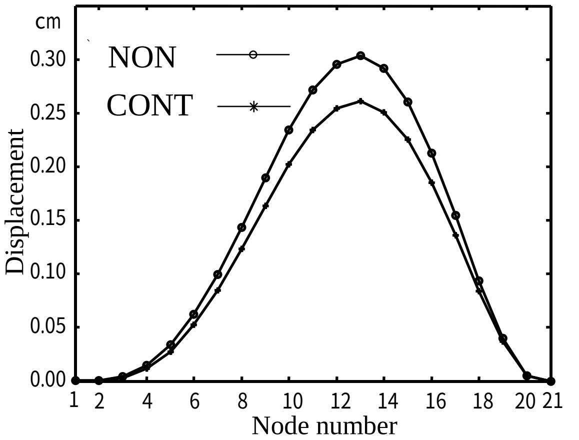

Figure 9 Horizontal displacements (Rise 10m)

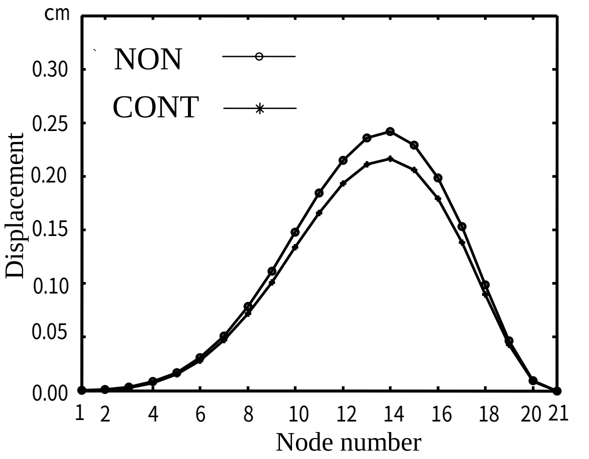

Figure 10 Horizontal displacements (Rise 14m)

C. Time histories of the damping ratios

The time histories of damping ratios are shown in the Figure 11, 12 and 13, respectively.

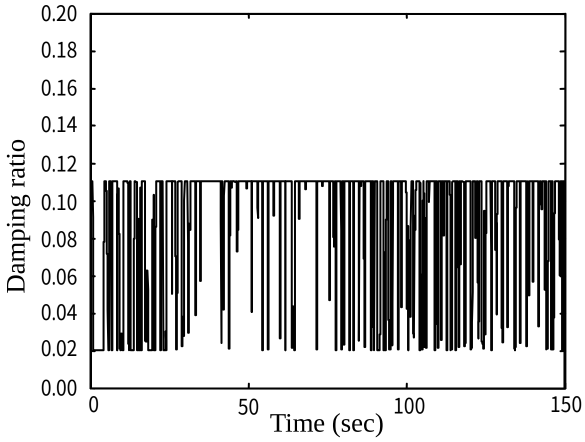

Figure 11　Damping ratios (Rise 6 m)

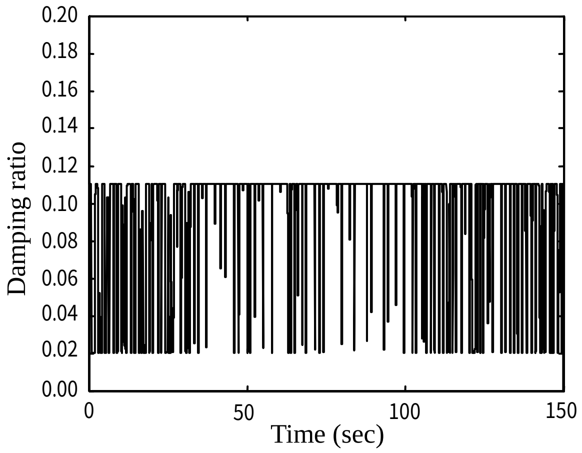

Figure 12　Damping ratios (Rise 10 m)

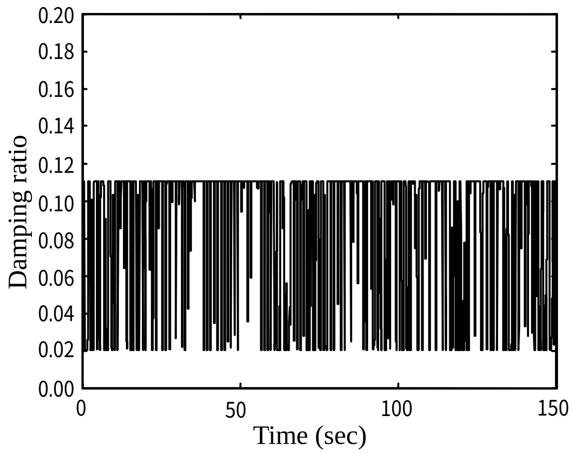

Figure 13　Damping ratios (Rise 14 m)

D. Maximum values

The maximum values of the results NON and CONT are shown in Tables 3 and 4, and the mean values of the damping ratios are shown in Table 5.

Table 3　Maximum vertical displacements u*

Rise	NON	CONT
6 m	2.87 cm	2.62 cm
10 m	1.60 cm	1.36 cm
14 m	0.85 cm	0.77 cm

Table 4　Maximum horizontal displacements w*

Rise	NON	CONT
6 m	0.28 cm	0.26 cm
10 m	0.30 cm	0.26 cm
14 m	0.24 cm	0.22 cm

Table 5　Mean values of damping ratios

Rise	Damping ratio
6 m	0.089
10 m	0.091
14 m	0.085

VIII. OBSERVATIONS

The following analytical results are obtained from the research.

1) With respect to the maximum response displacement in the vertical directions, the controlled (CONT) results of each rise 6m, 10m and 14m of the shell are reduced by 9%, 15% and 9% of the non-controlled (NON) ones, respectively.
2) With respect to the maximum response displacement in the horizontal directions, the controlled (CONT) results of each rise 6m, 10m and 14m of the shell are reduced by 7%, 13% and 8% of the non-controlled (NON) ones, respectively.
3) The mean value of damping ratio is 0.09.

IX. CONCLUSIONS

The displacements in the shell under the controlled results are smaller than those of the non-controlled ones. Though the rises of shells are difference, the mean values of damping ratios are same. The proposed neuronal vibration control method diminishes the vibration of the shell subjected to seismic forces.

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REFERENCES

[1] Nishimura, T. and Shingu, K., “Study on Dynamic Response of Rotational Shells with Edge Beams Subjected to Seismic Forces in the Vertical and Horizontal Directions”, Transaction of the Architectural Institute of Japan, Vol.326, pp47−59, 1983 (in Japanese)

[2] Freeman, J., Simulating Neural Networks with Mathematica, Addison-Wesley, 1994

[3] Shingu, K and Fukushima, K, “Study on Fuzzy Control of Shells Subjected to Seismic Forces”, Journal of Japan Society for Fuzzy Theory and Systems, Vol.5, No.3, pp650-662, 1993, (in Japanese)