

# Aseismic structural planning system by fuzzy network

H. Kawamura, A. Tani & H. Kambara  
 Kobe University, Japan

**ABSTRACT:**By using a fuzzy network proposed in this paper, aseismic structural planning can be performed considering human subjective evaluations and uncertain numerical values such as earthquake loading, design variables, structural responses, structural damage, economy, safety, function and so on. Case studies on R/C structures are carried out and the results show the effectiveness of the fuzzy network.

## 1. INTRODUCTION

In aseismic structural planning, it is inevitable to deal with human subjective evaluations and uncertain numerical values regarding future events. To take into account these characteristics the authors already proposed probabilistic and fuzzy evaluation methods for the aseismic capacity of R/C structures (Kawamura, Yamada, Tani and Teramoto 1985, Kawamura, Teramoto, Tani and Yamada 1986). Furthermore, a fuzzy expert system for aseismic evaluation and planning of R/C structures was constructed by the authors. (Kawamura, Tani, Matsumoto, Tsunoda and Yamada 1988). In this paper, a more intelligent and general fuzzy expert system is proposed by using a new concept of fuzzy network composed of many fuzzy systems (Zadeh 1971).

## 2. FUZZY NETWORK

Fuzzy network is composed of fuzzy systems (Zadeh 1971) and shown, e.g., in Fig.1. The variables A, B, C and D are inputs or outputs of the STATE 1, and they comprise a fuzzy system. The variables A, B, C and D are described with fuzzy sets expressed by vectors and the STATE 1 is described with fuzzy relation expressed by matrix. If D is nominated for an output, in this system D is given by

$$A \circ (B \circ (C \circ \text{STATE 1})) = D \quad (1)$$

where  $\circ$  means the max-mix operation (Zadeh 1965) which replaces the summation-product operation in matrices. The other variables and states in Fig.1 are also defined in the same manner as mentioned above. If D is nominated for an output in

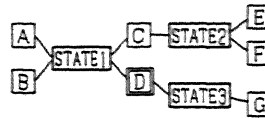


Fig.1 Fuzzy Network

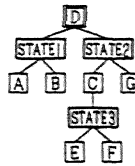


Fig.2 Transformed Fuzzy Hierarchy

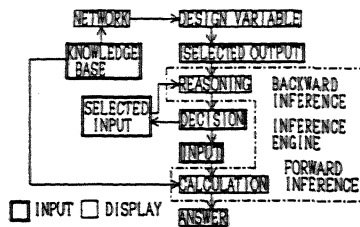


Fig.3 System Flow

this total fuzzy network, then D is obtained according to the restructured hierarchy shown in Fig.2.

To perform the procedure mentioned above automatically and intelligently in aseismic structural planning, a flow of expert systems is employed here as shown in Fig.3. According to the flow, users can select and obtain necessary outputs arbitrarily, e.g.,

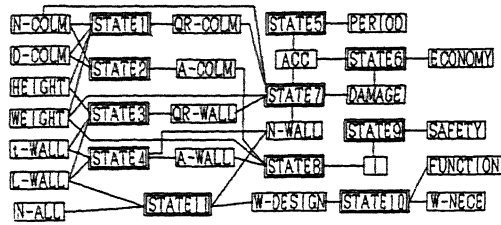


Fig. 4 Fuzzy Network for Structural Planning

Table 1 Variables

N-COLM	: Number of Columns
D-COLM	: Depth of Column Sections
HEIGHT	: Height of Columns
WEIGHT	: Seismic Weight of Buildings
I-WALL	: Thickness of Shear Walls
L-WALL	: Span Length of Shear Walls
N-ALL	: Total Number of Shear Wall Units
Q-R-COLM	: Force-Deformation Relation of Columns
A-colm	: Sectional Area of Columns
Q-R-WALL	: Force-Deformation Relation of Shear Walls
A-WALL	: Sectional Area of Shear Walls
ACC	: Acceleration Amplitude of Ground Motions
N-WALL	: Necessary Number of Shear Wall Units
W-DESIGN	: Design Length of Opening of Shear Walls
W-NECE	: Necessary Length of Opening of Shear Walls
ECONOMY	: Satisfactory Degree of Economy
SAFETY	: Satisfactory Degree of Safety
FUNCTION	: Satisfactory Degree of Function
PERIOD	: Return Period
DAHAGE	: Damage Factor
I	: Importance Factor

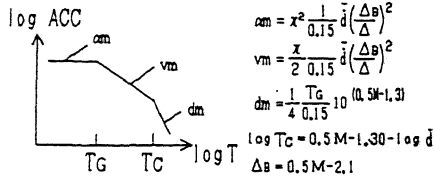


Fig. 5 Ground Motion Spectrum

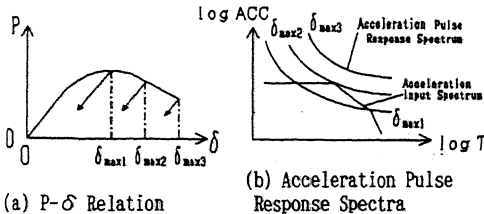


Fig. 6 Acceleration Pulse Response Method

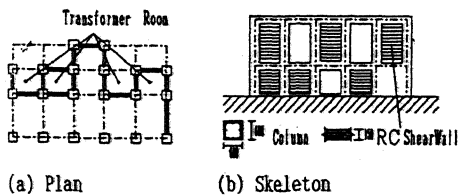


Fig. 7 Standard R/C-Transformer Substation

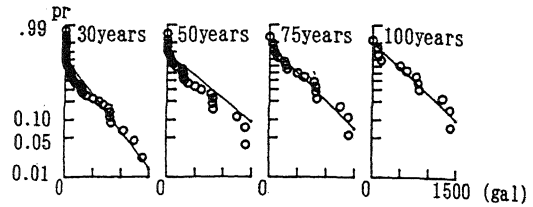


Fig. 8 Extreme Distributions of ACC

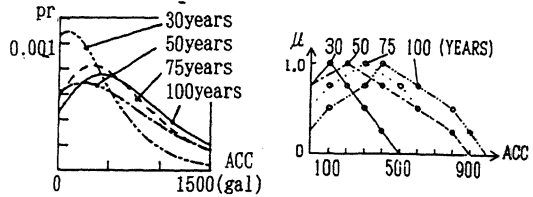


Fig. 9 (a) Probability Density Functions

Fig. 9 (b) Assumed Membership Functions

design variables or safety evaluations. Structural planning can be divided into two parts, i.e., (1) optimization in which optimal design variables are obtained and (2) evaluation in which safety, economy and function are evaluated.

In this paper, a fuzzy network for R/C structures is constructed as shown in Fig. 4. Variables in fuzzy network are shown in Table 1.

### 3 EVALUATIONS OF EARTHQUAKE INPUTS AND STRUCTURAL RESPONSES

The most important and decisive factors in the fuzzy network for aseismic structural design are PERIOD, ACC and STATE 5. In this paper, membership functions of ACC are defined using its probability density functions derived from its extreme distributions, i.e., Weibull distributions given by Eq. 2, obtained during each past return period, PERIOD.

$$\ln\{\ln(1/(1-F(ACC)))\} = a + b \cdot ACC \quad (2)$$

where  $F(ACC)$  is cumulative distribution function and ACC is earthquake acceleration.

In regard to STATE 5, the equation proposed by the authors (Kawamura, Yamada, Tani and Fujitani 1984) is employed for the calculation of ACC(gal) using earthquake magnitude  $M$  and epicentral distance  $\Delta$ (km) as shown in Fig. 5.

In aseismic structural planning, structural response analysis methods need speediness rather than strictness. In regard to STATE 7, for simplicity, seismic structural responses are obtained approximately

as maximal monotonic responses using acceleration pulse response analysis method proposed by the authors (Kawamura, Yamada, Tani and Fujitani 1984) as shown in Fig.6. The maximal monotonic response  $\delta_{max2}$  in Fig.6(a) is decided, because the acceleration pulse response spectrum of  $\delta_{max2}$  is tangent to the input acceleration spectrum in Fig.6(b).

#### 4 CASE STUDY

##### 4.1 R/C Structure

In this case study, a standard type of R/C transfer substations (see Fig.7) of Kansai Electric Power Co.Ltd is employed for aseismic structural planning. This building is assumed to be located at Kobe City in Japan. Aseismic optimization and evaluation are performed in the X-longitudinal direction.

##### 4.2 Seismicity

Based on seismic data (Chronological scientific Tables 1989), the M, A sets around Kobe City ( $\Delta < 200$  Km) are collected and the maximal acceleration amplitudes ACC (cm in Fig.5) are calculated using the ground motion spectrum shown in Fig.5. The extreme distributions of ACC during each return period (year), 30, 50, 75 and 100 are shown in Fig.8, and their probability density functions are shown in Fig.9.(a) Normalizing these probability density functions and considering the standard deviations, the membership functions of ACC (Fig.9(b)) are assumed with parameters of return periods in this case study.

##### 4.3 Definitions of STATES

STATES 1-11 in Fig.4 are defined as follows.

STATE 1: Using the calculation method of force-deformation relations of R/C columns proposed by the authors (Kawamura, Yamada, Tani and Fujitani 1984).

STATE 2: STATE 2 is given by Eq.(3).

$$A-COLM = (D-COLM)^2 * (N-COLM). \quad (3)$$

STATE 3: Using the calculation method of force-deformation relations of R/C shear walls proposed by the authors (Kawamura, Yamada, Tani and Fujitani 1984).

STATE 4: STATE 4 is given by Eq.(4).

$$A-WALL = (N-COLM) * (t-WALL) * (L-WALL) \quad (4)$$

STATE 5: STATE 5 is given by the ground motion spectrum in Fig.5. and shown in Fig.9(b).

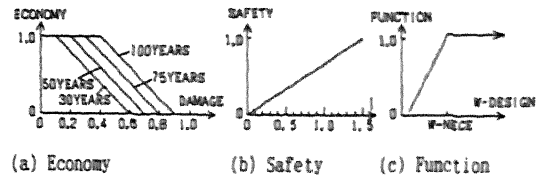


Fig.10 Assumed Evaluation

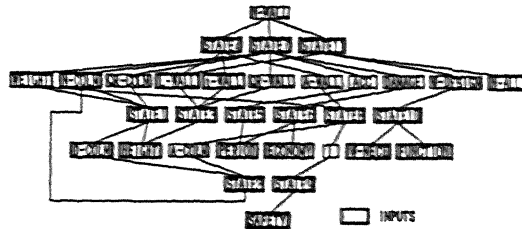


Fig.11 Transformed Fuzzy Hierarchy for Structural Optimization

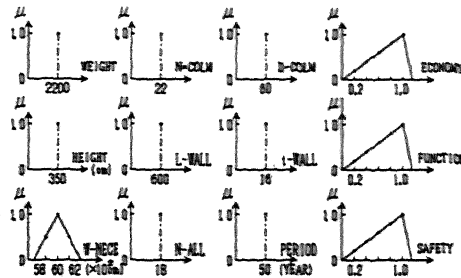


Fig.12 Inputs for Structural Optimization

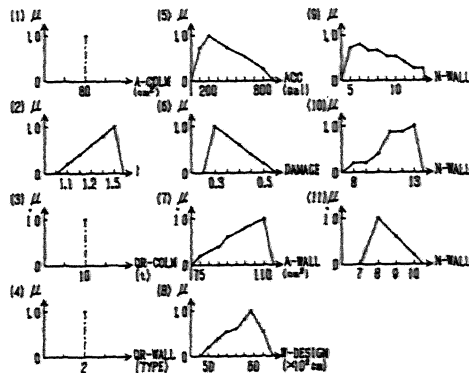


Fig.13 Calculated Variables in Structural Optimization

STATE 6: STATE 6 should be described from economic and social points of view. In this case study, it is assumed as shown in Fig. 10 (a).

STATE 7: STATE 7 is given by the accelera-

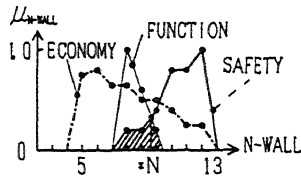


Fig.14 Decision of Optimal Number of Shear Wall Units

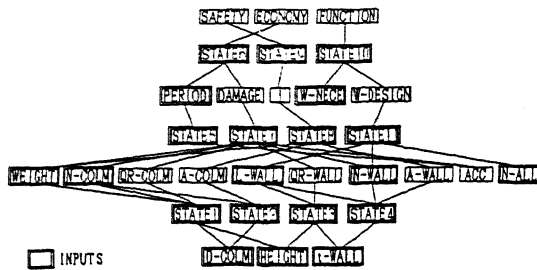


Fig.15 Transformed Fuzzy Hierarchy for Structural Evaluation

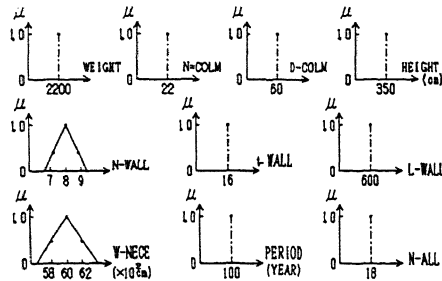


Fig.16 Inputs for Structural Evaluation

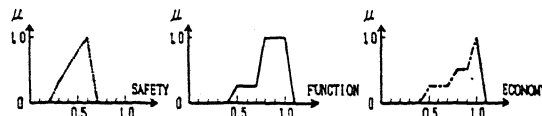


Fig.17 Evaluation of Economy, Safety and Function

tion pulse response analysis (Kawamura, Yamada, Tani and Fujitani 1984) shown in Fig.6. Damage factor DAMAGE is defined by  $DAMAGE = \delta_{max}/\delta_y$  where  $\delta_y$  is the maximum-strength deformation.

STATE 8: In this case study, importance factor I is calculated by Eq.(5).

$$25*(A-WALL)+7*(A-COLM)=WEIGHT*I \quad (5)$$

which is referred to the Japanese Building standard Law.

STATE 9: STATE 9 should be assumed from structural and engineering points of view.

It is shown in Fig.10(b).

STATE 10: STATE 10 should be assumed from architectural, social points of view. It is shown in Fig.10(c).

STATE 11: STATE 11 is given by Eq.(6).

$$(N-WALL)=(N-ALL)-(W-DESIGN)/(L-WALL) \quad (6)$$

#### 4.4 Aseismic Optimization

Aseismic optimization is performed with respect to optimal number of shear wall units. If N-WALL in Fig.4 is nominated for the final output, then the fuzzy network is transformed into a fuzzy hierarchy such as shown in Fig.11. Considering the properties of the R/C structure and using the inputs described with fuzzy sets shown in Fig.12, calculated variables in structural optimization are obtained as shown in Fig.13. Fig.14 shows the region of optimal numbers of shear wall units illustrated with membership functions given by maximizing decision (Bellman and Zadeh 1970), which means the optimal number is about 9-10.

#### 4.5 Aseismic Evaluation

Aseismic evaluation is performed regarding economy, safety and function. If ECONOMY SAFETY and FUNCTION are nominated for the final outputs, then the fuzzy network in Fig.4 is transformed into a fuzzy hierarchy such as shown in Fig.15. Using the inputs described with fuzzy sets shown in Fig.16. Fig.17 shows the final evaluations of economy, safety and function illustrated with fuzzy sets given by maximizing decision, which means they are in good conditions except safety.

#### 5 CONCLUSIONS

In this paper, a fuzzy network for aseismic structural planning is proposed and applied to structural optimization and evaluations of a R/C building. Case studies show the following things;

(1) Fuzzy networks can simultaneously include many kinds of factors necessary for aseismic structural planning, e.g., earthquake inputs, structural responses and evaluations.

(2) Every factor in fuzzy networks described with fuzzy sets and/or fuzzy relations can express expert subjective evaluations and uncertain numerical values and functions.

(3) Once a fuzzy network is constructed, users can obtain necessary outputs arbitrarily and automatically by means of maximizing decision.

(4) When high level CAD systems are added to the fuzzy network, it will become a very

man-machine friendly expert system for aseismic structural design.

#### Acknowledgement

Authors are grateful to Kansai Electric Power Co. Ltd. and Newjtec Co. Ltd. for their financial and data supports.

#### References

- Bellman, T.E., and Zadeh, L.A. 1970. Decision-Making in a Fuzzy Environment. *Management Science*, Vol.17, 1970, 11 B-141-164.
- National Astronomical Observatory (ed.). 1989. *Chronological Scientific Tables*.: 816-846.
- Kawamura, H., Yamada, M., Tani, A. and Teramoto, T. 1985. Aseismic reliability of buildings -In stochastic consideration of seismicity and structural fracture-, *Proc. of 4th International Conference on Structural Safety and Reliability (ICOSSAR'85)*, Vol.II: II-187-196.
- Kawamura, H., Yamada, M., Tani, A., and Fujitani, H. 1984. Regional Evaluation of Seismic Damages of Reinforced Concrete Buildings, *Proc. 8WCEE*, Vol.4, San Francisco, U.S.A.: 647-654.
- Kawamura, H., Teramoto, T., Tani, A. and Yamada, M. 1986. Fuzzy and Probabilistic Optimum Aseismic Design of Structures, *IABSE Symposium, Preliminary Report*, Tokyo, Japan: 141-148.
- Kawamura, H., Tani, A., Matsumoto, S., Tsunoda, K. and Yamada, M. 1988. Optimum aseismic design of buildings based production rule and fuzzy theory, *Proc. of 9th World Conference on Earthquake Engineering (9WCEE)*, Vol.V: V-1025-1030.
- Zadeh, L.A. 1965. Fuzzy sets, *Information and Control*, 8: 338-353.
- Zadeh, L.A. 1971. Toward on Theory of Fuzzy System, in *Aspects of Network and Systems Theory* (Ed., by Kalman, R.E., Declaris, N., Holt, Richard and Winston, Inc.: 469-490.