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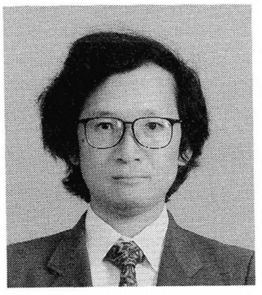
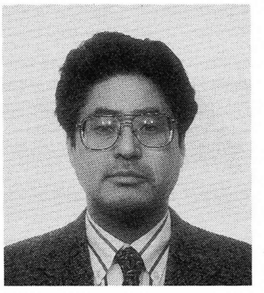
# Inverse Analysis of Esthetic Evaluation of Landscaped Concrete Retaining Wall


Noboru YASUDA　Yasuo CHIKADA　Manabu MATSUSHIMA　Tameo KOBORI

This paper, aimed at judging the scenery evaluation of green-covered concrete retaining walls, proposes the application of a method based on a fuzzy set theory, from a subjective point of view, to those cases of assessment which depend on the experience or sense of evaluators. Based on the results of a questionnaire set out to expert researchers, it also deals with a study on an inverse analysis using a genetic algorithm in attempt to give an objective support to, and identify explanatory factors of, the membership functions and importance coefficients in the fuzzy set theory which have been empirically set in the past.

*Key Words: scenery evaluation, concrete structures, planted, fuzzy set theory, genetic algorithm*

Mr. Noboru YASUDA is senior research engineer, Power Engineering R & D center, Tokyo Electric Power Co.,Ltd. He graduated Waseda University in 1977. His research interests include durability of concrete, concrete material and application of AI to various engineering problems.

Prof. Yasuo CHIKADTA is an associate professor, Dept. of Civil Engineering, Kanazawa University. He received his Doctor of Engineering Degree From Kyoto University in 1990. His research interests are bridge maintenance problems.

Dr. Manabu MATSUSHIMA is senior research engineer, R & D Dept., Tokyo Electric Power Services CO., Ltd. He received his Doctor of Engineering Degree from Tokyo Denki University in 1994. His research interests are applications of reliability theory to RC structures.

Prof. Tameo KOBORI is a professor ,Dept. of Civil Engineering, Kanazawa University. He received his Doctor of Engineering Degree from Kyoto University in 1968. His research interests are bridge engineering and regional planning.

## 1. Introduction

The construction of concrete structures is continuing as an important means of building up social infrastructure, and heavy reliance on concrete materials is expected to continue in the years ahead for reasons of durability and economics. Meanwhile, micro-environmental problems in and around urban areas have become issue of along with the global macro-environment leading to the current trend placing priority on the psychological as well as physical aspects of measures to cope with these problems.

Compared with the physical aspects, which comprise the preservation of ecosystems, the improvement of microclimates, and the control of air pollution resulting from such causes as carbon dioxide emissions and other harmful exhaust gases, the psychological aspects focus on the concept of environmental assessment as regards peace of mind, feelings of familiarity, and other elements of amenity, particularly esthetics or landscaping.

The esthetics evaluation of concrete structures is apt to be significantly affected by subjective sense or individual experience because there are no clear-cut distinctions among individual taste or judgments and esthetic requirements differ among individuals. The differentiation of these elements, even if expressed quantitatively, depends largely on the subjective choices of individuals based on their experience. In performing esthetic evaluations, therefore, it may be argued that judgment should be made from a subjective standpoint, wherever necessary, instead of pursuing the development of a method which seeks judgment from an objective point of view using the conventional practice of categorization. In 1965, the concept of fuzzy sets was proposed by L. A. Zadeh [1)] as a technique to mathematically deal with such subjective uncertainties. Also in the area of civil engineering, efforts have been made to apply a fuzzy set theory to the evaluation of physical properties of structures or materials and to the assessment of the aging deterioration and yield strength of structures. Shimizu and others [2)] have applied the fuzzy set theory to the classification of rock beds and evaluated its adaptability to this purpose. One of the authors of this paper [3)] has also applied the fuzzy set theory to evaluating the aging degradation of concrete.

This paper deals with a research project aimed at judging the esthetic evaluation of planted, or landscaped, concrete retaining walls and, as such, it proposes a method based on fuzzy set theory from the subjective standpoint discussed above. [4),5)] Such concrete structures are assessed in terms of functionality as well, but this paper proposes an evaluation method focusing on their esthetic or landscaping aspects .

To objectively determine the form of membership functions and their importance coefficients as required by fussy set theory, an attempt was also made as part of the research project to identify various explanatory factors by inverse analysis based on a genetic algorithm (GA) [6),7),8)]aluated values and total evaluation levels obtained from a questionnaire on 120 cases.

## 2. Items of Esthetic Evaluation

The desire is for a total system which is geared to making "evaluations aimed at environmental harmony" along with such safety considerations as strength, deformation, and durability - a primary consideration in maintenance and management - which form part of the planning and design philosophy of all structures including those of concrete.

To solve the questions mentioned at the beginning of this paper, and especially the relationship between plants and vegetation the natural realm and concrete structures ( artificial objects) a study will have to be conducted to find the physical effects they have on each other. Accordingly, prior selection of engineering methods and the development of special technologies relating to interactions are essential elements of evaluation aimed at environmental harmony. In the area of esthetic evaluation, which represents the psychological aspect of environmental protection measures, various studies have been conducted on problems concerning cities and the living environment and many examples are given in published reports. [9),10),11),12)] Among the different types of evaluation aimed at environmental harmony, therefore, this paper focuses on esthetic evaluation.

As shown in Figure 1, the overall impression of a landscaped concrete structure is apparently formed by the integration of three factors which harmonize with one another as individual elements with their own respective purposes and functions: ① the structure being assessed (a concrete retaining wall); ② the state of greenery resulting from landscaping; and ③ the surrounding environment. [11)] Humans, when evaluating scenery, map these physical elements onto their own mental model. Taking into account the relationship between these individual elements and their natural harmony, we selected items for evaluation in this research project. More specifically, we prepared the evaluation items described in Table 1, on the bases of past studies [11),12)]and other available information as reference data. With regard to overall evaluation - overall impression of the view - some attempts have been made to evaluate esthetic by color in another field dealing with similar psychological aspects of the environmental issue. Accordingly, we decided to adopt the results of these activities. In an overall evaluation of esthetics involves not only each persons own internal values of scenery but also relative values throughout human society comprising: ① scenic value; ② social value; ③ technological value; and ④ economic value. In this paper, however, the internal values are defined as components of the "overall evaluation" while the relative values are left out of consideration.

"Color sensation" is often used as a general term for psychological effects or impressions (images) in the area of coloring. These effects are determined by the method of free association, in which subjects are requested to report all words that come to mind as a result of experiences or stimuli arising from each of various colors shown. Based on the findings of studies by Ogiso and Inui [13)] and by Tomizuka's group, [14)] among various research efforts in this field, a total of 591 words have been identified as epithets suggested by stimuli from colors. In our study, 20 adjectives with particular relevance to landscaped concrete retaining walls were selected from these words based on the results of a questionnaire completed by experts in landscape engineering. These words were further reduced to 10, as listed in Table 2, after rating their significance by the repertoire grid method. The first (stable) and second (likable) of these final choices were used as adjectives for overall evaluation of esthetics.

## 3. Evaluation of Esthetic Level Based on Fuzzy Set Theory

### (1) Evaluation Procedure

In general, the items of evaluation are often qualitative. Even if they are expressed quantitatively, it is hard to set clear boundaries since they depend largely on the subjective evaluation of individuals. The aim of this study was to develop a method of esthetic evaluation that takes into account the "vagueness" resulting from this dependence of each evaluation item on the subjective response of evaluators, i.e., the disparities in individual judgments.

Table 1. Items of Esthetic Evaluation of Landscaped Concrete Retaining Wall

| Category | | Item of evaluation | Rating | No. |
|---|---|---|---|---|
| Landscaping | Arrangement | Is the landscaped area appropriate? | Sufficient<br>Insufficient | 1 |
| | | Is the method of combining different types of trees reasonable? | Yes<br>No | 2 |
| | | Do you think consideration was given to the creation of a three-dimensional effect? | Yes<br>No | 3 |
| | Shape and size | Is the shape of trees appropriate? | Yes<br>No | 4 |
| | | Is the height of trees well-balanced? | Yes<br>No | 5 |
| | | Is the tree density appropriate? | Yes<br>No | 6 |
| | Coloring | Do the planted trees match the color of the background? | Yes<br>No | 7 |
| | Sense of seasons | Does the view give a sense of the seasons? | Yes<br>No | 8 |
| Esthetics of the wall | Material | Is the material of the wall good or poor? | Good<br>Poor | 9 |
| | Shape and size | Is the shape of the wall good or poor? | Good<br>Poor | 10 |
| | Texture | Is the surface texture of the wall good or poor? | Good<br>Poor | 11 |
| Harmony | Landscaping and environment | Does the landscaping go well with the surrounding topography? | Yes<br>No | 12 |
| | Environment and wall | Does the retaining wall go with the surrounding environment? | Yes<br>No | 13 |
| | Wall and landscaping | Are the artificial objects and nature in harmony? | Yes<br>No | 14 |
| Overall evaluation | | Does the view look stable? | Yes<br>No | 15 |
| | | Is it likable? | Yes<br>No | 16 |

[Rating scale]

(An example)

Very Poor | Poor | Rather poor | Neutral | Rather good | Good | Very good

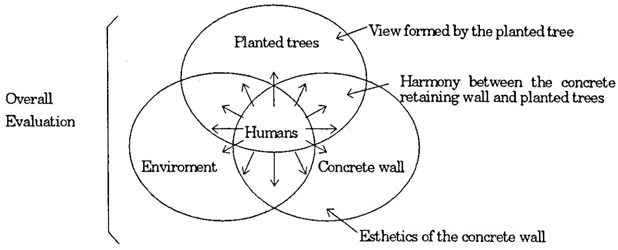



Fig. 1. Esthetic Evaluation of Landscaped Concrete Retaining Wall [11)]

Table 2. Epithets Used for Overall Evaluation

| Order | Epithet | Response rate |
|---|---|---|
| 1 | Stable | 86 % |
| 2 | Likable | 83 % |
| 3 | Serene | 79 % |
| 4 | Comfortable | 67 % |
| 5 | Refreshing | 61 % |
| 6 | Orderly | 60 % |
| 7 | Clean / Neat | 55 % |
| 8 | Natural | 54 % |
| 9 | Pleasant | 45 % |
| 10 | Splendid | 38 % |

Figure 2 is a flowchart representing a study on the evaluation of esthetic levels based on fuzzy set theory. As indicated in this block diagram, ① the items of evaluation affecting the scenery $X_{iL}$ (14 items in Table 1) were taken from past studies; ② the membership function $\mu_{iL}$ (Cn) is set on the rating for each of the selected evaluation items; ③ then the importance coefficient $W_{iL}$ is set for each of the evaluation items $X_{iL}$; ④ the membership function $\mu_R(C_n)$ for esthetic evaluation of the structure being assessed is set along with other membership functions; ⑤ the membership function $\mu_{ZL}(C_n)$ for the scenic level is set for use as an integrated; ⑥ fuzzy integration of the function $\mu_R(C_n)$ is performed using a fuzzy measure to determine the fuzzy expected value F(L) for the esthetic level of the structure; and ⑦ the esthetic level $S_L$ is determined by converting the fuzzy expected value calculated in ⑥ into a non-fuzzy set.

(2) Setting of Membership Functions for Items of Esthetic Evaluation

Ratings for each of the evaluation items mentioned in Table 1 are represented qualitatively, and as such, boundaries between these ratings are indistinct and set on vague grounds. If the response to the question - "Is the material of the wall good or poor?" - in Item 9 is divided into seven grades - A: Very poor; B: Poor; C: Rather poor; D: Neutral (or average); E: Rather good; F: Good; and G: Very good, for instance, judgment of the boundaries among these choices depends on the subjective response of individual evaluators. In this study, the vagueness of the boundaries among these grades was dealt with as a fuzzy set and the whole set was defined as in Equation (1) below by dividing the rating scale into 12 equal portions from 0.0 to 6.0:

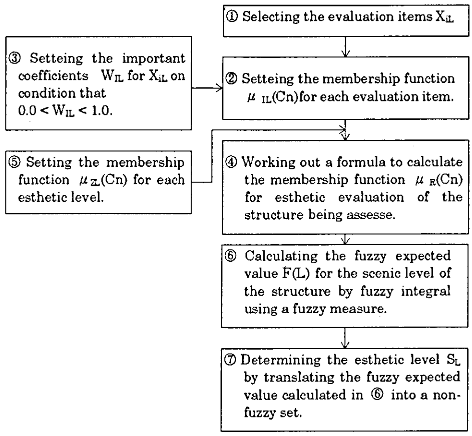



Fig.2 Flowchart of Process to Determine Esthetic Level of Structure.

$$C_N = \{0.0, 0.5, 1.0, \cdots, 5.5, 6.0\} (N = 0 \sim 12) \tag{1}$$

Each element of the whole set $C_N$ is an indicator of esthetic evaluation. The smaller the value of this element, the lower is its esthetic value, and conversely, the larger its value, the higher the scenery rating is.

An attempt was made to define the division of ratings for each evaluation item as a fuzzy set. It was assumed that the rating for each of the evaluation items in Table 1 could be divided into seven grades, ranging from A to G, and replaced by a fuzzy set. The rating was divided into seven grades because this type of division, as adopted in the standard deviation method as well, is considered well matched to the inherent rating scale used by humans. Usually, esthetics are evaluated by a combination or combinations of different evaluation items which are interrelated, but because of the above assumption, these items were dealt with independently of one another in this study. More specifically, seven rating grades were set for each of the evaluation items $X_{iL}$ ($i = 1 \sim 14$) and these grades were given as fuzzy sets $X_{iL}$ ($L = A \sim G$). Then the rating grades ($L = A \sim G$) originally stated in words could be defined as fuzzy sets [15]:

A: Very poor; $X_{iA} = 1.0/0.0 + 0.5/0.5$
B: Poor; $X_{iB} = 0.5/0.5 + 1.0/1.0 + 0.5/1.5$
C: Rather poor; $X_{iC} = 0.5/1.5 + 1.0/2.0 + 0.5/2.5$
D: Average; $X_{iD} = 0.5/2.5 + 1.0/3.0 + 0.5/3.5$
E: Rather good; $X_{iE} = 0.5/3.5 + 1.0/4.0 + 0.5/4.5$
F: Good; $X_{iF} = 0.5/4.5 + 1.0/5.0 + 0.5/5.5$
G: Very good; $X_{iG} = 0.5/5.5 + 1.0/6.0$

The membership function for $X_{iL}$, if given as $\mu_{XiL}(c_n)(c_n \in C_n)$, can be presented as in Figure 3. This diagram is typical of the fuzzy sets used for the study. Use of fuzzy sets thus enables us to quantitatively represent the vagueness involved in the selection of rating grades. It can be expected, however, that the results of evaluation may vary, depending on how this membership function is set. Therefore, the form of membership function described in Figure 3 should be considered the initial value, and in actual cases of evaluation, it should be adjusted according to the subjective judgment of individual evaluators.

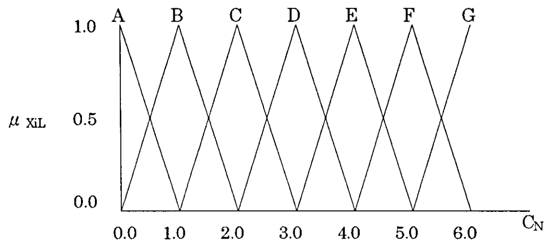



Fig. 3. Profile of Fuzzy Membership Function for Evaluation Item

(3) Setting of Importance Coefficients for Evaluation Items

The degree of influence an individual evaluation item has on the overall evaluation of esthetics differs from item to item. Accordingly, an importance coefficient $W_{iL}$ ranging from 0 to 1 was applied to each evaluation item in this study. It must be noted here that, like the membership function mentioned above, the importance coefficient should also be adjusted according to the subjective judgment of individual evaluators.

(4) Assessment of Fuzzy Expected Values for Esthetic Evaluation

This section deals with a method of determining an expected value for esthetic evaluation (as represented by the appropriate level from A through G and therefore called the "esthetic level" in the subsequent paragraphs) from the results of rating each item of evaluation. Since this decision generally depends on the subjective judgment of individual evaluators, it is hard to explain the process of thinking involved in determining the final esthetic level for each item. In order to clearly describe this process, an attempt is made in this paper to determine a fuzzy expected value for the esthetic level of the structure to be assessed, using the fuzzy set theory.

a) Fuzzy Set for Esthetic Level

First, a fuzzy set for the esthetic level of the structure to be assessed is to be found using the results of rating each item of evaluation and its importance coefficient. In other words, the membership function $\mu_R(C_n)$, which indicates the degree of belonging to the esthetic level, is calculated with the membership function $\mu_{XiL}(C_n)$ for the rating grade L as determined by the evaluator and with its importance coefficient $W_{iL}$. In this study, the equation for calculating the membership function $\mu_R(C_n)$ was defined as follows:

$$\mu_R(Cn) = \bigvee_{i=1}^{14} W_{iL} \cdot \mu_{xiL}(Cn) \tag{2}$$

Where $W_{iL}$ is the importance coefficient and $\mu_{XiL}(C_n)$ is the membership function for the rating grade L.

Equation (2) means that the influence on the membership function $\mu_R(C_n)$ can be explained in terms of the greatest factor. Thus the equation for calculating $\mu_R(C_n)$ is defined subjectively by the sense and experience of individual evaluators.

b) Fuzzy Measure[17),18)]

While a fuzzy set expresses the vagueness of what is meant by the object or term it describes, a fuzzy measure indicates the vagueness of rating results. In this study, we adopted the fuzzy measure g-$\lambda$ as a rating scale for the vagueness of the results. This fuzzy measure is defined as in Equation (3) below with $\lambda$ as a parameter:

$$\left.\begin{array}{l} g_\lambda(E_0) = g_1 \\ g_\lambda(E_i) = g_i + (E_{i-1}) + \lambda \cdot g_i \cdot g_\lambda(E_{i-1}) \\ \qquad\qquad (-1\langle\lambda\langle\infty, i = 0 \sim 12) \end{array}\right] \tag{3}$$

Where $E_i = \{C_0, C_1, C_2, \ldots, C_i\}$, representing a subset for $C_N$, and $g_i$ is the fuzzy density ($0.0<g_i<1.0$) which can be written as:

$$g_i = \alpha \cdot \mu_R(C_i) \tag{4}$$

Where $\alpha$ is a constant for normalizing $g_i$. After the parameter $\lambda$ is given, it can be determined as follows:

$$1 = \begin{bmatrix} \sum_{i=0}^{12} g_i & \lambda = 0.0 \\ \lambda^{-1}\left[\prod_{i=0}^{12}(1+\lambda \cdot g_i) - 1\right] & \lambda \neq 0.0 \end{bmatrix} \tag{5}$$

Equation (5) is a restricting expression for $g_i$ which, with $\lambda$ as a parameter; serves as a scale for the multiplicity of $E_i$. Where $\lambda > 0.0$, $g_\lambda(E_i) > g_i + g_\lambda(E_{i-1})$, resulting in a superior additive condition with priority placed on a higher evaluation level. If $\lambda < 0.0$, on the other hand, $g_\lambda(E_i) < g_i + g_\lambda(E_{i-1})$, bringing about an inferior additive condition with priority on a lower evaluation level. If $\lambda = 0.0$, meanwhile, $g_\lambda(E_i) = g_i + g_\lambda(E_{i-1})$, leading to an additive condition where the fuzzy measure is equal to the probability measure.

c) Evaluation of Esthetic Level by Fuzzy Integration

In this method, esthetic evaluation is performed by a fuzzy integration that treats the membership function for each rating grade as an integrated. The value of $g_\lambda(E_i)$ can be determined from $\mu_R(C_n)$ using Equation (3). Meanwhile, the fuzzy expected value F(L) can be determined by integrating the membership function $\mu_{ZL}(C_n)$ for the esthetic level with $g_\lambda(E_i)$. Accordingly, the fuzzy expected value F(L) for each scenic level L can be written as

$$F(L) = \int \mu_{zL} \cdot g_\lambda = \bigvee_{i=0}^{12}\left[\left(\bigwedge_{n=0}^{i} \mu_{zL}(C_n)\right) \wedge g_\lambda(E_i)\right] \tag{6}$$

d) Determination of Esthetic Level

The esthetic level $S_L$ is determined from the fuzzy expected value thus calculated for each esthetic level L. As a method of converting fuzzy expected values into non-fuzzy ones, the esthetic level was determined in this study by finding the center of gravity of the distribution of these expected values, as shown in Equation (7):

$$S_L = \frac{\sum_{L=1}^{7} F(L) \cdot L}{\sum_{L=1}^{7} F(L)} \tag{7}$$

4. Evaluation of Esthetics by Questionnaire

(1) Questionnaire

The questionnaire set out in this study called on respondents to evaluate the structures shown in the attached photographs with respect to the esthetic evaluation items specified in Table 1, using the seven-grade rating scale described above. In addition to photographs, certain other methods, especially those making use of photomontages or computer graphics, are available for presenting materials for esthetic evaluations of the structures. To preclude the probability that the performance of such presentations might indirectly affect in the results of the evaluation, we restricted this study to the use of photographs. Since variations in the surroundings or in the type of structure might give the respondents different impressions of the esthetics due to changes in overall harmony or field of view, a decision was made to use only one category of structures, i.e., concrete retaining walls, in the questionnaire. Arrangements were also made to ensure that the shooting angle and the proportion of the picture occupied by the structure would be held constant in all photographs(about 45 degrees and 50%, respectively) as far as possible. In addition, efforts were made to have all photographs give approximately equal treatment to the surroundings.

The structures selected for esthetic evaluation were 12 landscaped concrete retaining walls, as shown in Photo 1 and 2, located near residential streets on the outskirts of Tokyo. Their major features are given in the footnotes to each photograph. Ten male and female researchers (roughly equally divided among three age brackets - 20s, 30s, and 40s) were selected from people engaged in studies relating to landscape engineering to do the esthetic evaluation. Ten evaluators were chosen because we thought this was sufficient number to model the whole population from samples in any category of topics that involves such wide disparities as esthetic evaluations. [19]

(2) Results of Evaluation

Of the results of the esthetic evaluation obtained in the questionnaire, the overall evaluation concerning esthetic stability is summarized in Table 3. In addition to "stable," this overall evaluation covers another item - "likable" - but this section deals with findings only on "stable" because the results of evaluation and inverse analysis on these two items show approximately the same behavior. The findings of the inverse analysis will be discussed later in more detail. As is apparent from the table, overall ratings on any particular photograph differ significantly among evaluators. A look at the overall spread of ratings in Figure 4 indicates that, although they tend to concentrate in the middle grades, they are spread over all grades from 1 to 7. According to the relationship between average value and standard deviation of the ratings, shown in Figure 5, the average represents an intermediate assessment of the esthetics in each photograph, corresponding to "rather poor," "rather good" or "neutral" (or average) on the specified rating scale. The coincidence of the average value with these intermediate grades means that all or most of the evaluators gave no extreme ratings, such as "very good" or "very poor" or "good" or "poor," on any of the pictures assessed.

In general, many evaluators tend to agree in rating very poor esthetics, but when giving good ratings, especially in photographs featuring novel ideas or individuality, they tend to be divided. According to the questionnaire findings, the evaluators' views did not differ significantly on those photographs which were given a relatively high average value of overall evaluation (a rating close to 7 on the scale) or on those which were given a relatively low average (a rating close to 1). Meanwhile, their views differed rather widely on those which were given intermediate ratings. This is mainly because the concrete retaining walls evaluated in the questionnaire are not independent structures assessed alone, but are essentially required to harmonize with the surrounding rows of houses and other buildings. Accordingly, the evaluators' opinion did not differ appreciably on those structures which had relatively good esthetics as in the case of those which were given a relatively poor evaluation. On the other hand, there were rather wide differences in opinion on those structures which received intermediate ratings, presumably because the rating scale was divided into seven grades.

Table 3. Average Value and Standard Deviation of Ratings

| Photos | Evaluator numbers | | | | | | | | | | Average | SD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | | |
| I | 5 | 3 | 2 | 4 | 5 | 4 | 4 | 4 | 5 | 5 | 4.1 | 0.94 |
| II | 5 | 5 | 4 | 4 | 5 | 5 | 5 | 4 | 2 | 3 | 4.2 | 0.98 |
| III | 6 | 6 | 4 | 6 | 6 | 5 | 6 | 4 | 5 | 5 | 5.3 | 0.78 |
| IV | 6 | 5 | 2 | 5 | 5 | 6 | 5 | 6 | 3 | 5 | 4.8 | 1.25 |
| V | 4 | 3 | 1 | 4 | 3 | 3 | 5 | 7 | 4 | 4 | 3.8 | 1.47 |
| VI | 3 | 5 | 5 | 5 | 1 | 4 | 3 | 2 | 6 | 5 | 3.9 | 1.51 |
| VII | 2 | 2 | 1 | 3 | 2 | 3 | 3 | 2 | 5 | 3 | 2.6 | 1.02 |
| VIII | 5 | 5 | 5 | 5 | 3 | 5 | 5 | 4 | 4 | 3 | 4.4 | 0.80 |
| IX | 5 | 2 | 2 | 4 | 3 | 4 | 3 | 1 | 6 | 5 | 3.5 | 1.50 |
| X | 4 | 5 | 2 | 4 | 1 | 4 | 2 | 4 | 1 | 3 | 3.0 | 1.34 |
| XI | 5 | 3 | 5 | 5 | 3 | 5 | 4 | 6 | 2 | 3 | 4.1 | 1.22 |
| XII | 5 | 3 | 1 | 5 | 5 | 5 | 2 | 2 | 5 | 5 | 3.8 | 1.54 |

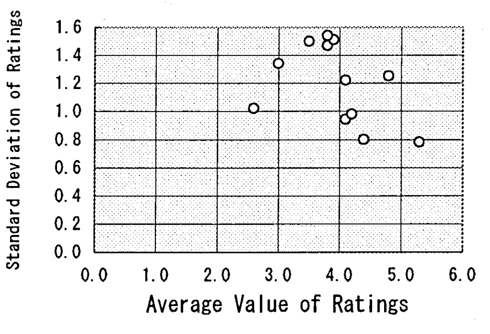
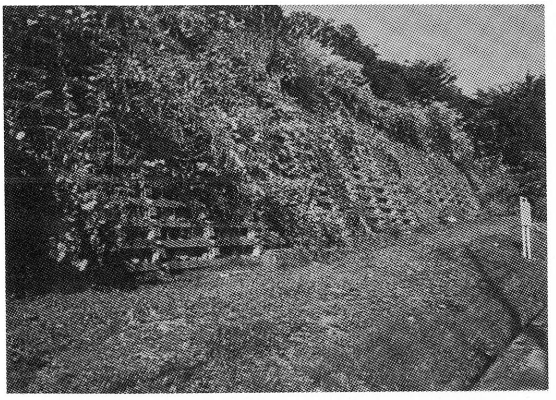
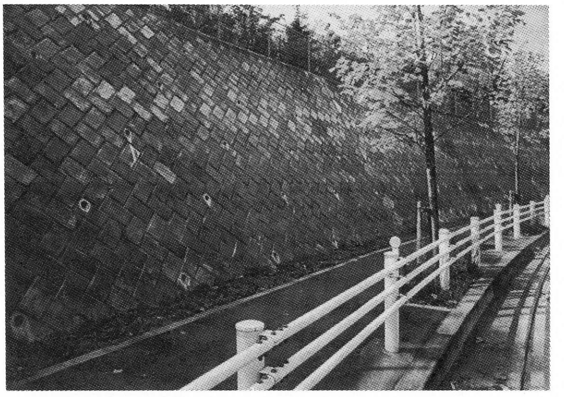



Fig. 4. Disparities in Rating



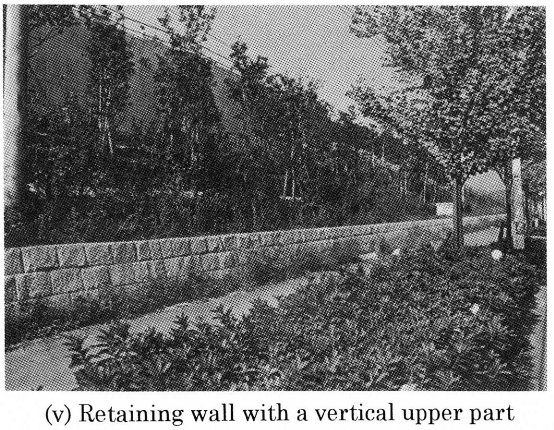
(i) Lattice block wall back-filled with rubble, with a grass strip at the top of the slope



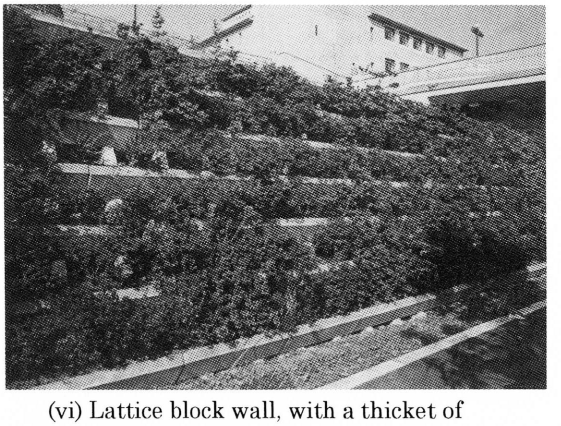
(ii) Standard rectangular block wall, with roadside trees planted at wide intervals

(iii) Retaining wall using blocks finished like natural stone, with trees planted at close intervals on the top of the slope

(iv) Retaining wall using blocks finished like natural stone, with trees planted on the top of the slope

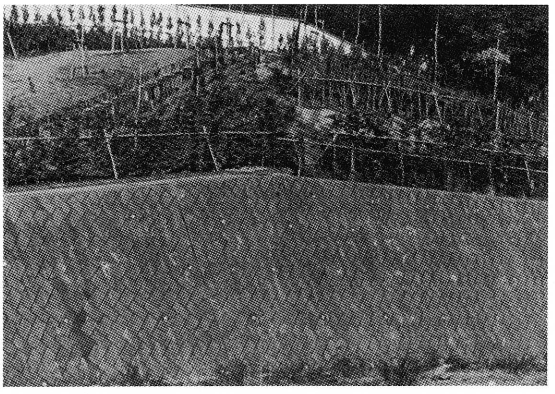


(v) Retaining wall with a vertical upper part and a block-built lower part, and having two intermediate terraces of trees



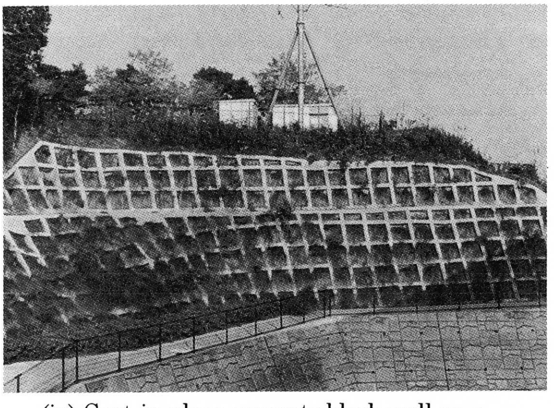
(vi) Lattice block wall, with a thicket of azaleas in the framework.

Photo 1. Concrete Retaining Walls Used for Esthetic Evaluation

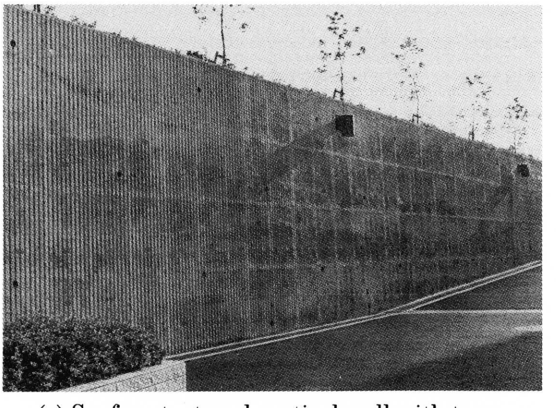


(vii) Standard rectangular block wall, with trees planted on the top of the slope

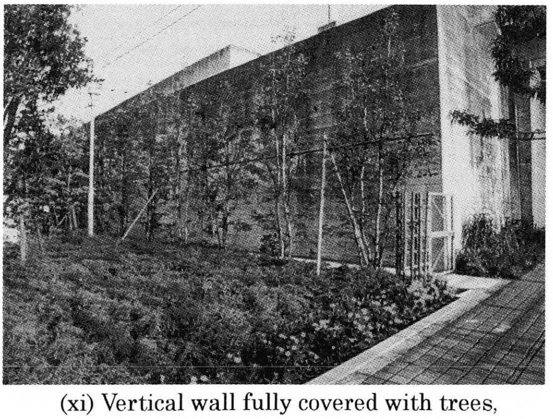
(viii) Vertical upper wall partly covered with a vine; some thickets at the bottom



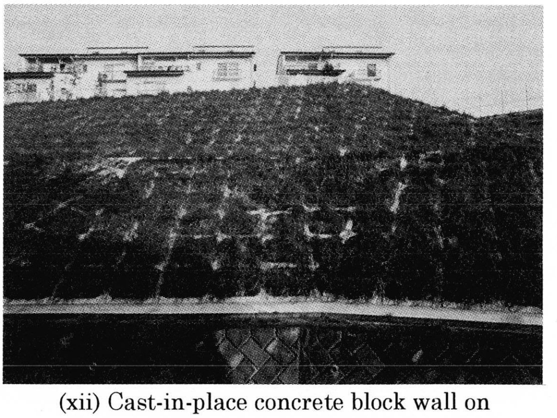
(ix) Cast-in-place concrete block wall on a steep slope, with a stable-like building in the framework



(x) Surface-textured vertical wall with trees planted at wide intervals on the top and some thickets at the bottom



(xi) Vertical wall fully covered with trees, plus some thickets arranged like a garden at the bottom



(xii) Cast-in-place concrete block wall on a gentle slope, with stable-like buildings in the framework

Photo 2. Concrete Retaining Walls Used for Esthetic Evaluation

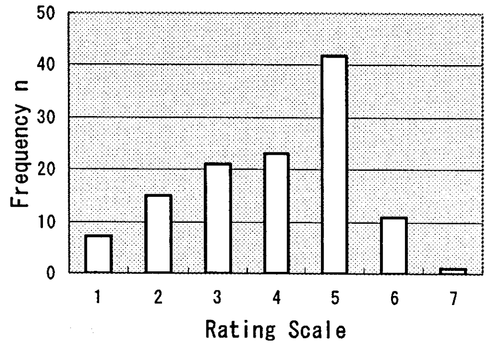


Fig. 5. Relation between Average Value and Standard Deviation of Ratings

## 5. Inverse Analysis with Genetic Algorithm

### (1) Procedure for Inverse Analysis

The genetic algorithm [20),21)], a probabilistic method derived from biological evolution, is now applied to many problems, including the optimization of combinations.

Considering the evolution of life to be a process of the survival of the fittest, as first proposed by Charles Darwin, GA deems the existing groups of living entities to be the quasi-fittest with the greater adaptability to the environment. This algorithm aims at providing a method of optimization by substituting simple mathematical models for the propagation/selection, crossing-over, and mutation processes in the evolution of living things. Recently, the algorithm has come to the fore as an effective method of solving problems concerning the optimization of combinations. Since GA itself is described in detail in the available literature, the discussion here focuses on an attempt to determine subjectively-set values of importance coefficients, the forms of membership functions, and the parameter $\lambda$ for calculating fuzzy measures, using an inverse analysis based on the results of a questionnaire set out to experts in this field. This will also provide a tool with which to study the possibility of determining the judgment characteristics of experts. GA is used as a method of solution for the inverse analysis, which is a problem of optimizing combinations that have many variables.

Figure 6 shows a flowchart of this inverse analysis with GA. The process consists of the following steps: ① the importance coefficient $W_{iL}$, membership function $\mu_{XiL}$, and multiplicity scale $\lambda$ are changed in code as discrete variables - the variables corresponding to genes, combinations of which are dealt with as a sequence of lines, and individuals as a sequence of lines; ② the initial set consisting of two or more sequences of lines is considered; ③ its adaptability (the degree of satisfaction of an objective function) is evaluated; ④ those combinations of line sequences which have low adaptability are eliminated through selection based on the results of the evaluation; ⑤ the next-generation group is produced by gene manipulation, including crossing-over (exchange of subsequences of variables) and mutation (changes in the value of variables).

In this study, an attempt was made to form a sequence of lines with variables (corresponding to genes) for the unknown discrete parameters to be found, and to determine a fuzzy measure using assessed values for the 14 items specified in Table 1 based on one set of questionnaire results, i. Then the fuzzy value of evaluation $S_L(i)$ was found by fuzzy integration. From the fuzzy value thus

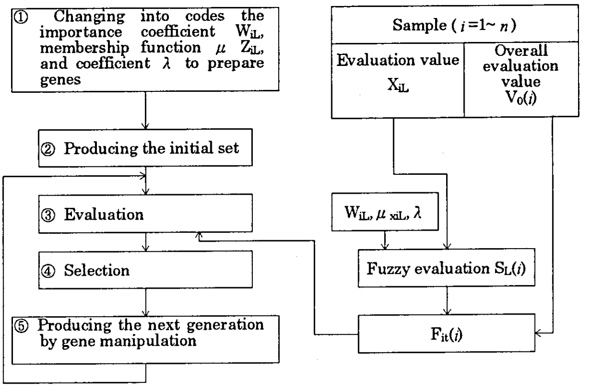



Fig. 6. Flowchart of Inverse Analysis Using GA

determined, and the overall evaluation value Vo(i) based on the findings of the questionnaire, the adaptability $F_{it}(i)$ was defined as Equation (8) in this study:

$$F_{it}(i) = 10 - |V_0(i) - S_L(i)| \tag{8}$$

This means that the adaptability reaches 10 when the two evaluations become exactly equal. Therefore, the adaptability $F_{sum}$ to n-sets of questionnaire results can be defined as:

$$F_{SUM}{}^2 = \frac{1}{n^2} \sum_{i=0}^{n} F_{it}(i)^2 \tag{9}$$

Thus the total adaptability Fsum to n-sets of questionnaire results can be defined as the optimum value 10, and generations can be altered out by GA to maximize its adaptability. In other words, the whole process is the problem of optimizing an objective function such that the value of $F_{sum}$ is maximized. Since this process involves many variables and long sequences of lines a parallel-dispersed version of GA was adopted in this study, as described later in more detail. With this prearrangement, an attempt was made to produce four groups of sequences of lines and to carry out the alteration of generations in each group by simple GA. In each generation, sequences of lines were exchanged between different groups in such a way that sequences of lines with low adaptability in one group would be replaced by high-adaptability sequences of lines from another. Since the range of adaptability within one generation was relatively small, the sequences of lines were so scaled that the minimum value of adaptability would be 1/3 of the maximum value. Selection was then performed by roulette.

The unknown parameters to be found were: ① importance coefficients; ② membership functions; and ③ the variable $\lambda$. Of these parameters, membership functions were so prepared that, as described in Figure 7, their multiplicity could be changed by varying their inclination. Arrangements were also made to express changes in the average value as well by changing the inclinations on the right and left sides independently of each other.

(2) Inverse Analysis

The importance coefficients were made discrete in pitches of 0.1 each over a range of 0.0 to 1.0, and the number of their available combinations was set at 1,114.

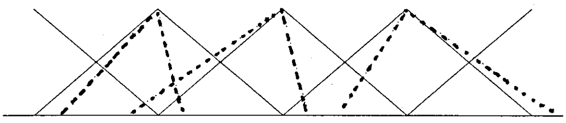


Fig. 7. Changes in Inclination of Membership Function

Table 4. CA Parameters

| Item | Value |
|---|---|
| Number of individuals | 100 |
| Rate of crossing-over | 0.8 |
| Rate of mutation | 0.03 |
| Number of generations | 1000 |
| Number of groups of line sequences | 4 |

Meanwhile, the membership functions were given the capability to vary their inclination on the right and left sides independently of each other at 28 different angles, and these parameters were made discrete as 282 = 784. The number of available combinations of variables was set at 78,498 because there were seven grades on the rating scale and 14 items of evaluation, i.e., 7 x 14 = 98. In addition, basic GA parameters were set as in Table 4.

Using the results of the questionnaire, an inverse analysis was made with GA. Figure 8 shows changes in the adaptability $F_{SUM}$ for each generation. As is apparent from the diagram, the adaptability increases gradually with a constant difference maintained between the average and worst values. The best value for the group becomes virtually stable at 1,000 generations, indicating that it settles satisfactorily. To verify the validity of this convergence value, a Monte Carlo simulation was performed using 10,000 random numbers. Figure. 9 shows the distribution of adaptability and compares the converged adaptability determined by GA with the result of the Monte Carlo simulation. The converged adaptability found by GA is 9.3 $\sigma$ away from the average value determined by the simulation, indicating that the adaptability is near the best value.

(3) Results of Inverse Analysis

Figure 10 shows the results of inverse analysis on the importance coefficient for each of the specified evaluation items. The importance coefficients for "coloring" and "harmony of landscaping" were found to have high sensitivity, indicating that items which have been_specified evaluation items. The importance coefficients for "coloring" and "harmony of landscaping" were found to have high sensitivity, indicating that items which have been landscaping" were found to have high sensitivity, indicating that items which have been traditionally considered important

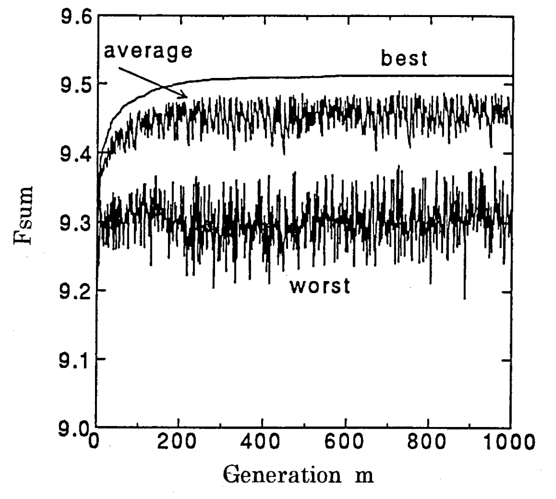



Fig. 8. Changes in Adaptability $F_{SUM}$ for Each Generation

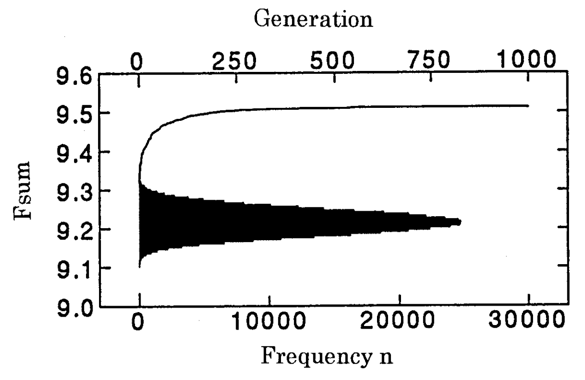



Fig. 9. Comparison of GA and Monte Carlo Simulation

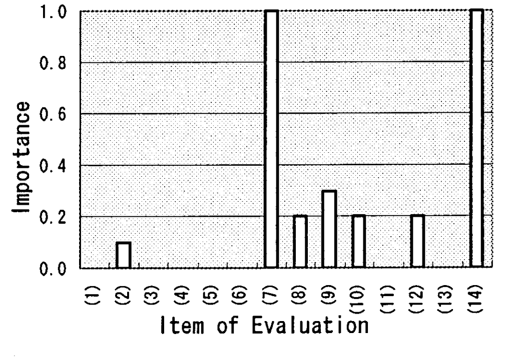



Fig. 10. Results of Inverse Analysis Relating to Importance

elements of esthetics were verified by the inverse analysis. Meanwhile, the importance coefficients for half of the 14 items were found to have no sensitivity at all. Particularly notable is that the height and density of trees and some other items concerning tree planting, which appear to be readily translatable into physical measures, are not necessarily suitable for use as typical elements of esthetic evaluation. In evaluating esthetics, according to the analysis findings, harmony of the structures and landscaping with the surroundings is a more important requirement than the arrangement or outline of the planted trees - elements of evaluation relating to the landscaping itself.

The results of the inverse analysis of membership functions are summarized in Figure. 11. The fuzzy functions, originally given symmetrically on the right and left sides, were found to have become asymmetric, and the parts showing severe asymmetry were related to those evaluation items which were given extreme ratings, such as "very good" or "very poor" or "good" or "poor", or which were found to have high sensitivities as noted above. From this, it is predicted that an extremely high or low rating given to the evaluation item to be examined will have the greatest influence on the overall evaluation and such influence will increase nonlinearly. Figures. 12 and 13 show the errors between the overall evaluation by inverse analysis and the results of the questionnaire as classified by evaluator and by photograph, respectively. The error $\varepsilon$ can be defined as:

$$\varepsilon^2 = \frac{1}{n^2} \sum_{i=1}^{n} \left[ s_L(i) - v_0(i) \right]^2 \tag{10}$$

The errors as divided by evaluator range from 0.46 to 1.04, varying somewhat according to evaluator. It may be argued that evaluators with smaller errors made stable, correct evaluations, but on the whole, errors in rating were around 1.0. If the use of a seven-grade rating scale for the overall evaluation is taken into account, the results indicate that a proper esthetic evaluation was made during this study. Errors classified by photograph have little characteristic behavior, but significant errors were found with some photographs, implying that some difficult elements were included in the evaluation. Disparities in overall evaluation in the "Esthetic Evaluation Based on Questionnaire in Section 4 tended to decrease if the photograph to be assessed was given high ratings. The tendency for increased disparity in evaluating the esthetics of certain photographs was reduced by correcting the importance coefficients and the inclinations of the membership functions using GA. Apparently these corrections helped to ensure a more stable evaluation of structures.

Incidentally, the value of $\lambda$ calculated by the inverse operation reached as high as 10,000, indicating that all items had superior additive characters.

## 6. Conclusion

This study, aimed at reviewing the esthetic evaluation of landscaped concrete retaining walls, proposed a new evaluation method using a theory of fuzzy sets from a subjective point of view.

In order to subjectively determine the form of membership functions and their importance coefficients in applying fuzzy set theory to scenery evaluation, an attempt was made to perform an inverse analysis with a genetic algorithm, using various evaluations as well as overall evaluation levels obtained from a questionnaire. The results of this analysis and the other findings of this

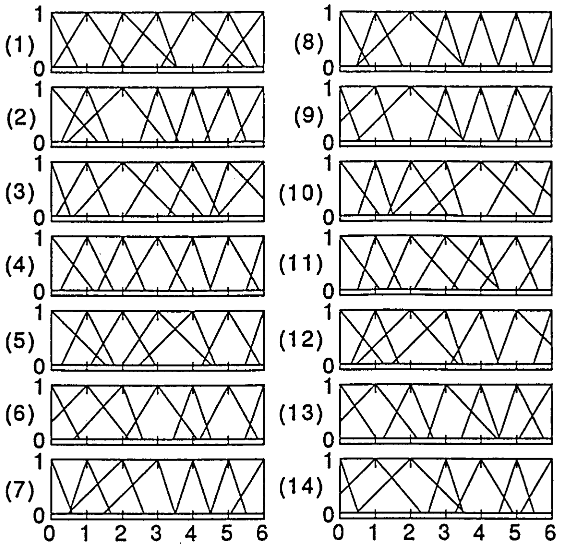



Fig. 11. Results of Inverse Analysis of Membership Functions

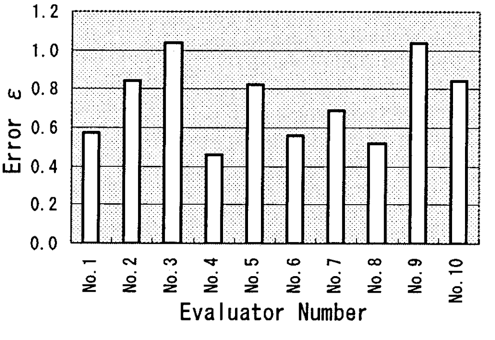



Fig. 12. Errors Classified by Evaluator

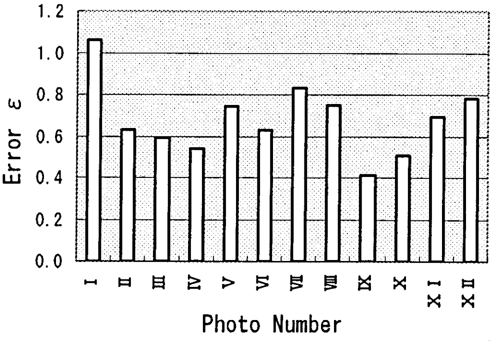



Fig. 13. Errors Divided by Photograph

study may be summarized as follows:

(1) Use of the fuzzy set theory for esthetic evaluation of landscaped concrete retaining walls gives the ability to quantify the process of thinking in assessing esthetics and to quantitatively represent a subjective evaluation.

(2) Changes in adaptability by an inverse analysis using GA helped yield a value fairly close to the optimum level, even in crossings of around 200 generations. In those instances where the optimum solution in a strict sense is not required, as in this study, it was found that inverse analysis provides an effective, efficient tool.

(3) Among importance coefficients determined by a GA-based inverse analysis, those showing high sensitivity are such evaluation items as "coloring" and "harmony of landscaping". This means that an esthetic evaluation can be explained with a very few factors. The findings also indicate that the density of trees and some other elements which can be readily converted into physical measures are not necessarily important in the evaluation of esthetic.

Incidentally, errors in a GA-based analysis may vary according to the structure or evaluator. As in the questionnaire set out during this study, evaluators with roughly the same level of expertise should be selected for this type of analysis because the difficulty of evaluation or the stability of evaluators' responses under the influence of the type of structures being assessed may serve as disturbing factors in dealing with problems which require subjective judgment.

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