1. INTRODUCTION

In recent years, citizens have become actively involved in infrastructure development. The government responsibility in ensuring transparent planning processes and explaining required matters is much heavier than ever. Also, much attention has been paid to the government in terms of its capacity to create processes to reach a consensus among the citizens and what they do to consensus building, in addition to providing information and gathering opinions. The government has made efforts in establishing the mechanism of reflecting citizens’ opinions, and it is important to continue activities to fully function the mechanism.

Consensus building is a communication process taken when groups or members make a decision or take an action. Through this process, they coordinate their opinions, cooperate one another, and take a give-and-take approach. The process of consensus building involves various aspects such as planning, plan evaluation, reviewing by making improvement, and operation control. Consensus is absolutely necessary in all of these aspects [1].

Scene simulation using Virtual Reality Modeling Language (VRML), Geographic Information System (GIS) and Virtual Reality (VR) techniques are reported as major consensus-building techniques [2-5]. Research was also conducted where Self-Organizing Map (SOM) is used to visualize the relationship between design elements and people’s aesthetic feelings [6]. In another research, a system was created to help create an alternative plan required for consensus building [7-8]. Similarly, a system was created in another research to reflect residents’ opinions and aesthetic favors in order to smoothly present alternative plans to the residents and assist their decision making [9]. These are the examples to indicate that tools have been developed such as scene simulation and those visualizing alternative plans and evaluation results conducted when the existing scene components are partially changed.

During the process of consensus building, the government is supposed to prepare a wide range of alternative plans by gathering various opinions and to coordinate for finding trade-off solutions and assigning priority. At this time, discussions should be based on the aesthetic performance required by the citizens. This common base for discussions is established by defining what the citizens desire to the scene. By doing so, it is possible to maintain fairness among all the parties concerned while finding trade-off solutions or assigning priority, and to avoid cases where the result is disadvantageous only to a specific party.

Performance required by concerned parties during consensus building is so diverse and it depends on the business field, business stage, type of structure and regional characteristics. Therefore, such diverse performance has never been organized or incorporated into design so far. However, under the performance design system, since discussions are based on the performance matrix, it is necessary to break down the performance required under various construction environments into numerical values and to represent them on the performance matrix. Further, it is also essential to create a final design while obtaining agreement with the residents based on the performance matrix thus created. The series of design process mentioned above must be essentially taken to reach a consensus with residents on the basis of their involvement.
No research has been conducted so far where the performance that citizens or several parties desire to scene is defined to attempt a consensus using the performance matrix. If an approach to consensus building is established from the viewpoint of aesthetic performance, it can also be applied to design, renewal and maintenance, where great achievement is expected.

In this research, attempt has been made on Kansei engineering that has been widely used in product marketing. We apply Kansei engineering to aesthetic design of structure under the performance design system to smoothly build a consensus among residents. However, unlike product marketing, the assumed target in infrastructure development is an indefinite number of people and it is necessary to consider regional characteristics such as culture, history and climate as Kansei or aesthetic feelings. In the research conducted in the past [10-11], Kansei engineering [12] is restrictedly applied to scene as performance, whereas in this research, we attempt to apply Kansei engineering to consensus building under the performance design system.

More specifically, we focus on the bridge structure and present the method to create the aesthetic performance matrix associated with external factors (construction environments of the structure) and required level of performance (Kansei evaluation level). Then, construction environments such as urban area, mountainous area and coastal area are set as external factors to create performance matrix in terms of several aesthetic feelings such as “beautiful”, “never getting tired of looking at” and “harmonious”. Based on the matrix thus created, evaluation is verified among the parties concerned, and the result is used for consensus building about the bridge structure and aesthetic design.

In Section 2 below, the concept of aesthetic performance during performance design and the necessity of aesthetic performance matrix are explained. In Sections 3 and 4, the creation method of the aesthetic performance matrix and system establishment using Kansei database are explained, respectively. Finally in Section 5, the verification of the performance matrix and its relationship with aesthetic design are discussed.

2. AESTHETIC PERFORMANCE

2.1 Position of Scene in Performance Design

Activities in regard to performance design gained momentum in around 1998. The issue arose concerning harmonization between technical standards in such fields as civil engineering, construction, steel structure, concrete structure and foundation structure and corresponding international standards. To address this issue, the Ministry of Land, Infrastructure, Transport and Tourism (current name) issued “Basis of Structural Design for Buildings and Public Works [13]” in March 2002 as a guideline for design in civil engineering and construction fields. The Ministry specified that engineering standards covering design works under the control of the Ministry be organized or revised in line with this guideline. In this guideline, however, scene (landscape in the text) is eliminated from the scope as follows: Whereas the design of a structure is a comprehensive work taking account of not only safety, serviceability and restorability but also landscape, impact on the environment, economic efficiency, etc., this code only covers “structural design” considering serviceability, safety, restorability, etc., as specified in Basic requirements of design.

For long, not much efforts were made for consensus building, but the government took the first action in January 1999 by issuing “Ministry of Construction: Promotion of Communication-Based Infrastructure Development [14]”. This policy emphasizes the importance of consensus building, and communication between the government and the public was facilitated since then.

Concurrently, discussions regarding performance design started in around 1999. Japan Society of Civil Engineers (JSCE) issued “Guidelines for Basic Design of Environmental-Load-Reduction-Oriented Structures and Guidelines for Detail Design of Environmental-Load-Reduction-Oriented Structures [15]” in April 2001, defining the required design functions and performance as shown in Figure 1. It is the first guideline that represents the performance necessary for scene as function in hierarchy. Whereas conventionally required functions are discussed just in terms of economy, safety, serviceability and ease of construction, it is worth noting that scene was defined as one of the required environ-
mental functions at the same level as environmental load reduction. Since then, scene characteristics as both function and performance began to be discussed under the one design system.

2.2 Necessity of Aesthetic Performance Matrix

Now that scene is defined as function in the guideline [15] mentioned above, the next step is to covert it into performance, then specific design, and physical characteristics. This conversion process from required performance to specific design is called concept breakdown model, which is commonly adopted in product marketing in fields such as automobiles [3]. However, when applying the concept breakdown model to infrastructure development, various issues arise. One is that consensus building is required at every stage, and another is that it is difficult to create the evaluation criterion that is common to all people concerned and all stages because people evaluate scene differently. The last is that whereas objectivity, transparency and fairness are important factors in evaluations, there is no criterion under which judgment is made whether the required performance, a common base for discussing concept breakdown model, is satisfied.

Then, the performance matrix should be used to discuss whether the required performance is satisfied. In the U.S., the performance matrix is practically used already for the purpose of vibration-durable design (Figure 2). The performance matrix for the purpose of scene has not yet been available, but as consensus building becomes more common, it will be organized as a common base for discussing aesthetic functions and performance by all people concerned.

2.3 Performance Design System and Aesthetic Performance

JSCE issued a report on design code based on performance design [16]. In this report, JSCE requires that purpose and required performance be specified above performance rules (left column in Figure 3). According to the hierarchy, the review approach A, free design, or the review approach B, primitive design, are both available design methods. The notable characteristics of this performance design system are that it considers the system as necessary to further evaluate the reliability as a result of review for the required performance, which is in other words the target of the design (such as target performance, performance rules and required level by performance expression) [17]. Figure 3 shows the correspondence between the performance design system JSCE proposed and aesthetic design and performance. Katsuki pointed out in his research [17] that the system to re-evaluate the review result is important but difficult to create. The possible re-evaluation method for review result is to present citizens or users with an alternative plan and ask if it conforms to the design concept, for instance by means of questionnaire.

Figure 3 shows the flow chart where details of the structure are determined after the design concept is fixed. It is obviously important to build a consensus with citizens, residents or various people concerned and to clarify the purpose and required performance.

3. CREATION METHOD OF AESTHETIC PERFORMANCE MATRIX

3.1 Definition and Purpose of Aesthetic Performance

There is no approved method of defining aesthetic performance. It can be said that aesthetic performance is high if the gap is small between the image citizens, users, concerned people etc. have against the structure and the feeling they have when they see the actual structure.
The next question is how the aesthetic performance matrix is used. Possible cases where the matrix is used are when grade is assigned to the structure and when verification level is selected. Assigning grade to the structure is explained in reference to Figure 2. Whereas the standard structure does not require special consideration regarding scene (Basic Objective in Figure 2), a grade which is one level higher than that of the standard structure (Essential/Hazardous Objective in Figure 2) is assigned to the structure built on primary sight-seeing spots in need of special consideration regarding scene. On the other hand, selection of verification level is expressed as conformance degree of design element according to the level of aesthetic performance or as satisfaction level of people involved in the consensus building process. In the case of vibration-durable performance, Level-1 earthquake vibration is used for Bridge A to verify the vibration-durable performance “No damage” and Level-2 earthquake vibration is used to verify the vibration-durable performance “Prevention of critical damage”, whereas in Bridge B, the condition of Level-1 earthquake vibration is the same, but Level-2 earthquake vibration is used differently to verify the vibration-durable performance “Restricted damage”.

3.2 Creation of Performance Matrix

In this section, the creation method of the aesthetic performance matrix is explained. In the performance matrix, there is an intricate correlation between design elements in correspondence with various aesthetic feelings and wide level of concerned people.

What is the aesthetic performance required for consensus building like? In actual aesthetic design, consensus must be built against several aesthetic words converted from the design concept. Therefore, we assume that the lateral axis represents the conformance degree with the design concept. For instance, when the conformance degree with the design concept is 30%, 30% of the people concerned judge that the design concept is satisfied in terms of a particular aesthetic word. Further, we assume that the vertical axis represents the number of aesthetic words about which a certain group of people consider that the design concept is satisfied. Under this condition, the aesthetic performance matrix required for consensus building is shown in Figure 4. With evaluation graphs of concerned groups added, this matrix can be used for discussion for consensus building.

In Figure 4, in the case of structure ranked as important, realization of conformance degree of 70% or more with the design concept is significantly difficult in regard to all the aesthetic words. A case may even occur where a satisfactory solution cannot be found. On the contrary, in the case of structure ranked as standard, conformance degree of 70% or more for a certain group is achieved in terms of only one aesthetic word. Similarly, it is only 30% of conformity degree that satisfies all the three aesthetic words. Therefore, it is easier to find a satisfactory solution. There are three ranks on the lateral axis in Figure 4, but it may be two. If there are more aesthetic words converted from the design concept than those if Figure 4, they are added to the vertical axis.

The problem in Figure 4 is how to determine the conformance degree with the design concept. More specifically, the degree of 70% or 30% must be recognized as reasonable by those involved in consensus building.

3.3 Transition from Design Concept to Performance Matrix

Assuming that a design concept is assigned to a certain bridge, the process of creating the aesthetic performance matrix for consensus building is studied.

The example of aesthetic design for Bridge A used in references [7] and [8] is cited here and the specifications of Bridge A are as follows.

- Bridge length: 254.0 m
- Bridge grade: Class A bridge (TL-20)
- Superstructure: 4-span-connected steel non-composite box girder bridge
- Substructure: Wall type pier
- Span division: 56.40 m + 2@70.00 m + 56.40 m
- Width: Driveway 7.250 m, sidewalk 2.500 m
- Skewed angle: 70°00'00"
- Horizontal alignment: Straight
- Applicable specifications: Specifications for highway bridges issued by JAPAN ROAD ASSOCIATION in February 1990

This bridge was built across the river running through mountains. It was planned and designed to embrace and blend into its natural surroundings. Superstructure, substructure, and details (bridge deck, color, etc.) were studied based on the design concept specified separately. Figure 5 shows the design concept.
When the design concept of “Fusion with nature and a sense of unity” shown in Figure 5 is a primary aesthetic feeling, it needs to be converted into secondary aesthetic feelings, or descriptive feelings commonly understood by everyone. In this case, it is converted into three adjectives: natural, harmonious and merged into the background, where “natural” is derived from nature, “harmonious” from fusion, and “merged into the background” from a sense of unity. The secondary aesthetic feelings (adjectives) thus converted are supposed to be derived from the 43 adjectives collected from the questionnaire described in references [7] and [8]. This is because the relationship between the 43 adjectives and design elements have already been clarified according to the Hayashi’s quantification methods (category I). Here, the secondary aesthetic feelings are quantified as follows: “natural (+1)”, “harmonious (+1)” and “merged into the background (+1)”. The values in the parentheses are the weightings when input. There is no approved method of converting the concept into the n-th aesthetic feelings as mentioned above. In this research, the design concept was converted into any of the 43 adjectives that have a known relationship between the design elements and the evaluations [7].

Based on the above concept, the aesthetic performance matrix for Bridge A is created using the case in Figure 4. As in Figure 4, the lateral axis has the three conformance degrees with the design concepts. There are three esthetic words converted from the design concept: “natural (+1)”, “harmonious (+1)” and “merged into the background (+1)”, and the values in the parentheses are the weightings. Calculations are made on the number of the aesthetic words that are evaluated as 70%, 50% and 30% conforming to the design concept, respectively. The resulting dots plotted in applicable cells of the matrix are combined to obtain graphs, indicating the evaluation graph of each group concerned.

Figure 6 is such an example. The graphs show that in the case of bridge designers, they evaluate one aesthetic word as conforming to the design concept 70%, and two aesthetic words as conforming to the design concept 50%. The result, at this point, matches the standard curve. However, compared to the standard curve where there are three aesthetic words with conformance degree of 30% or more, they evaluate only two, considering one aesthetic word as less than 30%. The evaluation result of the female students is therefore also unacceptable, which means that an alternative plan must focus on the aesthetic word that was evaluated as less than 30%. In the case of male students, the graph showing their conformance evaluation satisfies the standard curve in terms of all the conformance degrees.

In this way, it is possible to visually understand the performance evaluation according to concerned groups by drawing evaluation graph of each group on the aesthetic performance matrix.

4. SYSTEM ESTABLISHMENT

In this research, Extensible Markup Language (XML) is used to systemize the performance matrix according to the subject. The reason of the adoption of XML is: (1) ease of data exchange with other systems; (2) ease of addition of questionnaire results regarding aesthetic evaluation by a new category of residents into database; and (3) compatibility with the use on the Internet, requiring only a browser to actuate the system, meaning that quick response can be made to residents as required in occasions such as public hearings held for consensus building. With regard to disclosure of information to the public, XML is compatible.
with the use on the Internet, accessible to anyone from anywhere.

The necessary data is obtained from the analysis results according to the Hayashi’s quantification methods (category I). It consists of scores by the categories of various subjects and 43 adjectives [8]. The data was all converted into XML.

Figure 7 shows an example of the XML instance file. It shows the analysis result according to the Hayashi’s quantification methods (category I) where the subject is female students and the adjective is “feminine”. There are score tags from 1 to 20 which correspond in number to the items, with partial correlation coefficient stored in each tag.

This XML data is opened in a browser and processed by Document Object Model (DOM) + Visual Basic (VB) script to enable calculation and display.

5. VERIFICATION

5.1 Verification by Means of Questionnaire

Another groups of people are tested regarding the impression of Bridge A when they see a picture. They consist of mechanical engineering students (10 females and males, respectively) and 7 bridge designers. They complete the questionnaire in accordance with five evaluation levels (-2, -1, 0, +1, and +2) by the semantic differential (SD) method. Table 1 shows the average of the scores obtained from the questionnaire. From this data, conformance degree with design concept is calculated using Equation (1). The questionnaire is completed in accordance with the five evaluation levels (-2, -1, 0, +1, and +2) and thus -2 is converted as -100 and +2 is converted as +100.

\[ I = Qt \cdot W \]  
(1)

\( I \) : Conformance degree with design concept (%)  
\( Qt \) : Converted value of questionnaire result (=a\cdot Q)  
\( Q \) : Questionnaire result (average from -2 to +2)  
\( a \) : Conversion coefficient (=200/4=50)  
\( W \) : Weighting

Furthermore, we verified the effectiveness of the consensus building method using the performance matrix by asking 10 designers involved in the consensus building process. As shown in Table 2, it is proved that the method discussed above is an essential and effective consensus building method.

5.2 Use of Performance Matrix at Alternative Plan Preparation for Consensus Building

In the process of aesthetic design, alternative plans for evaluation must be prepared for consensus building before undertaking questionnaire surveys. When preparing the alternative plans, care must be taken because the design elements having a big impact on the evaluation differ depending on the group concerned. In other words, if design concept is already fixed, it is possible to prepare alternative plans beforehand that would obtain better evaluation results by using the design elements that seem to be positively evaluated by the group concerned [7]. According to reference [7], the design elements are input as items/categories, and evaluation by adjectives is carried out by calculation using the scores analyzed in accordance with the Hayashi’s quantification methods (category I).

The precise calculation method is as follows: (1) select the
subject (female students, male students, and bridge designers); (2) select categories (from 1. main girder shape to 20. presence of obstacles); and (3) multiply the selected category (1 if selected, 0 if not selected) by the score according to adjectives. Reference to [7] is recommended for details. Tables 3 shows the result thus obtained, and Table 4 shows the conformance degree with the design concept obtained by conversion using Equation (1). Here, the conversion efficient is 200/2=100 considering the fluctuation width of the total score. The values are input from Table 4 and the performance matrix is obtained with the graph according to subject group plotted. For instance, in the case of female students, the resulting performance matrix is displayed on the screen as shown in Figure 8. The matrices for bridge designers and male students can be displayed in the same way just by changing the subject.

From Table 4 and Figure 8, the conformance degree of the female students fully satisfies the standard curve. However, it is not the case for the male students because their evaluation in regard to “harmonious” is low. In the case of bridge designers, if necessary for consensus building, alternative plans must be prepared by taking countermeasures to obtain better evaluation result. In particular, measures must be taken in order to obtain higher conformance degree in terms of the two aspects “natural” and “harmonious”. At this time, however, care must be taken to keep the evaluations by the female and male students to the same level.

6. CONCLUSION

In this research, attempt has been made to create the aesthetic performance matrix to smoothly build a consensus with residents in regard to aesthetic design under the performance design system. Under the performance design system, discussions have mainly focused on the safety, economy, serviceability, etc. based on the performance matrix, but even no performance matrix had been created in the field of aesthetic design. Although required aesthetic performance varies, consensus building among different concerned groups is achieved only when such various performance is broken down, quantified, and then represented on the performance matrix.

Specifically, we tried to expand the use of the performance matrix discussed under the performance design system to that for consensus building as aesthetic performance. We have proposed the performance rules based on the required performance level, and review and verification methods, etc. Further, we presented the creation method of the aesthetic performance matrix for consensus building in terms of several aesthetic feelings converted from the design concept. Finally, verification was made on consensus building among concerned parties using the aesthetic performance matrix.

The following issues remain.

1. Consensus building among the concerned groups should be attempted by referring to the result shown on the aesthetic performance matrix created. In other words, agreement must also be reached among the concerned parties on matters including the validity of the conformance degree with the design concept.

2. The method of converting primary and secondary aesthetic feelings from the design concept must be established. At this time, the study needs to cover the weighting method and how to consider the adjective “beautiful” as an aesthetic feeling including its weighting.

3. There is far more variety of feelings than those of the

<table>
<thead>
<tr>
<th>Table 3: Evaluation on category score of bridge A</th>
<th>a total of score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>female students</td>
</tr>
<tr>
<td>Natural</td>
<td>0.977</td>
</tr>
<tr>
<td>Harmony</td>
<td>0.335</td>
</tr>
<tr>
<td>Merged into background</td>
<td>0.852</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 4: Equality degree with a design concept</th>
<th>female students</th>
<th>male students</th>
<th>bridge designer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural</td>
<td>97.7</td>
<td>95.7</td>
<td>37.4</td>
</tr>
<tr>
<td>Harmony</td>
<td>33.5</td>
<td>24.2</td>
<td>26.2</td>
</tr>
<tr>
<td>Merged into background</td>
<td>85.2</td>
<td>78.4</td>
<td>64.6</td>
</tr>
<tr>
<td>The number more than equality degree 30%</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>The number more than equality degree 50%</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>The number more than equality degree 70%</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 8: Output (Aesthetic performance matrix) female students
students and bridge designers covered in this research. That is, feelings are different depending on whether the subjects are children, students, company employees, housewives, elderly people, and they differ even by sex and professions. It is necessary to accumulate these various feelings and enrich the Kansei database on which the research should be based.

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