5. NEW APPROACH TO BRIDGE LIFECYCLE MANAGEMENT SYSTEM

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Abstract: Bridge lifecycle has several stages including planning, design, fabrication, erection, service, maintenance, and demolition. In the existing bridge database management systems, the information of each stage is not efficiently used on other stages, which results in waste in time and efforts. In this research, a new type of bridge lifecycle management system is developed to overcome this problem. The system integrates geographic information, design data, and inspection data in a user-friendly multimedia environment. Several examples are discussed on the efficient usage of the system at each stage of the lifecycle.

Keywords: lifecycle management, GIS, object-oriented database, multimedia, network technology, seismic vulnerability assessment

1. Introduction

Bridge lifecycle has several stages including planning, design, fabrication, erection, service, maintenance, and demolition. Recently, research efforts have been focused on minimizing the maintenance and maximizing the life of a bridge. Environmental assessment and landscape of a bridge have been considered in the early planning and design stages in addition to the structural, functional and economic requirements. For the purpose of evaluating a bridge from all viewpoints, the structural information of a bridge, the environmental information around a bridge, the CO₂ emission during the construction of a bridge, and other information in a bridge lifecycle are necessary. However, it is very hard and time-consuming to collect, handle, and utilize these various kinds of information because it is generally available only in the paper form that is difficult to deal with using the computer and information technologies. On the other hand, although several databases have been developed for the purpose of bridge planning, bridge design, bridge construction, or bridge maintenance, it is difficult to integrate these separate databases and exchange information among them. It may be a possible strategy to solve this problem by developing a synthetic database including the information from all bridge lifecycle stages.

In this research, based on new information technologies, a bridge lifecycle management system is developed by integrating a geographic information system (GIS) module and an object-oriented database (OODB) module in a user-friendly environment. The object-oriented approach is adopted to represent the bridge structure. Each component of a bridge contains its related data such as design, inspection and maintenance, earthquake, and image data at each lifecycle stage including planning, design, fabrication, construction, maintenance, and demolition stages. Using the object-oriented approach, it is possible to add the inspection and

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Fig. 1 Bridge Lifecycle Information

maintenance data periodically to copies of the bridge objects. Furthermore, the use of GIS is becoming popular in the development of applications in various fields of civil engineering. In this paper, GIS is used to integrate the bridge data and other data related to roads, rivers, soils, etc. Finally, several application examples of the developed system will be discussed.

2. Bridge Management Information Types

In the present research, the information of 287 road bridges managed by Nagoya City is considered as an example. These bridges were constructed between 1931 and 1990, and their lengths are greater than 15m. The proportions of steel, PC, and RC bridges are about 54%, 33%, and 12%, respectively. Because the information of each stage of the bridge lifecycle has its own generation process and management style, and the amount and types of information increase with time, it is necessary to classify the information according to its generation process. In addition, the lifecycle analysis needs the integration of the data related to all lifecycle stages.

During the lifecycle of a bridge, five types of information are important. These are: (1) geographic information, (2) design information, (3) fabrication and construction information, (4) inspection and maintenance information, and (5) specifications information such as design and construction specifications. Because fabrication and construction information is the property of the fabrication and construction companies, it is not available to other parties involved in the bridge lifecycle. Furthermore, the specifications information is expressed in the form of text including tables, figures and equations. Therefore, the specifications information is difficult to be quantified from the technical point of view. Due to the above reasons, only geographic data, design data, and inspection and maintenance data are collected at present. Furthermore, in the present practice of bridge inspection, the detailed data related to the damage of bridge components such as cracks and rust, are documented not only as text explanation, but also by taking several pictures of the damage and arranging them in an album. These pictures are referred later to help in the visual understanding of the position, pattern, and development of the damages. As a result of the recent development of computer technology, it is becoming possible to save and process image data in the computer effectively. In addition, because the data of previous earthquakes such as the damages of bridges and their strengthening methods are very important for the seismic management of bridges, the information related to earthquakes is also collected as a special kind of inspection information. Therefore, in this system, geographic information, design information, inspection and maintenance information, image information, and earthquake information are considered.

The contents of each kind of information are classified as follows:

(1) Geographic Information

a) Topographic Information: including the coordinates information of roads, rivers, and bridges digitized from a 1:25000 district map;
b) Land Use Information: including grid data of 10 meter mesh in order to investigate the conditions at the bridge site; and
c) Subsoil Investigation Information: including the data of 4190 borings from the geotechnical data of the subsoil in Nagoya City.

(2) Design Information
a) Design Drawing Information: such as detailed design drawing; and
b) Numerical Information: such as components’ dimensions, loads, resistance, and material properties from the design calculation reports.

(3) Inspection and Maintenance Information
a) Inspection information: including the inspection results of bridges in the bridge inspection database and bridge seismic inspection database, and
b) Image information: including more than 5000 pictures of Nagoya City bridges.

(4) Earthquake Information
a) Earthquake Damage Information: such as investigation reports on several previous earthquakes including the Miyagiken-Oki Earthquake in 1978, the Nihonkai-Cluub Earthquake in 1983, the Kushiro-Oki Earthquake in 1993, and the Great Hanshin Earthquake in 1995;
b) Seismic Strengthening Information: including seismic strengthening report after the above mentioned earthquakes; and
c) Damage Image Information: such as pictures on damaged highway bridges after the 1995 Great Hanshin Earthquake.

Fig. 1 shows the relationship among the above five kinds of information and the bridge lifecycle. Because there are various types of information in each stage, the original formats of all kinds of information must be transformed to fit the purpose of lifecycle management. This also aims to utilize the available information of some bridges for managing other bridges of a network-level bridge system. An OODDB approach makes it possible that the bridge lifecycle information including design, inspection and maintenance, earthquake, and image information can be managed efficiently during the whole lifecycle from the planning stage to the demolition stage.

3. Bridge Management Database Development

(1) Geographic Information
In this research, a GIS software, ARC/INFO, is used to represent and process the previous mentioned geographic information. The geographic information can be used in each lifecycle stage and updated over time. GIS software offers spatial analysis and statistical analysis capabilities by integrating graphic processing and database functionality with a powerful user interface. GIS has the following five functions: (1) storing and retrieving data, (2) analyzing data, (3) displaying data, (4) relating separate infrastructure management databases, and (5) rapidly responding to questions given by the users about how the data are spatially related. These distinguished functions of GIS for handling geographic data fulfill the needs of a bridge management system. GIS separately manages topographic information and attribute information, and can join these two types of information. The graphical information of the map can be represented by raster or vector format. In the case of the vector format, the information related to the graphical features can be expressed using numbers and character strings that form a database. GIS was used as a platform in the previous research to perform seismic vulnerability assessment of highway bridges in a region.

Bridge attributes are from the above-mentioned bridge inspection database and bridge seismic inspection database. The data format is modified to the ARC/INFO format. Furthermore, the basic attributes of roads and rivers related to the bridges such as the traffic volume and river flow are also added to the database. The main geographical data coverages are: bridge coverage, road network coverage, river coverage, land use coverage, and soil coverage. (1) Bridge coverage: This coverage contains the locations and dimensions of the bridges such as the length and the width of a bridge. All bridges are digitized as a line feature. The data of the bridge structure and the inspection are represented in an object-oriented database and will be discussed later. (2) Road network coverage: This coverage has the layout of expressways, national, regional, and local roads in Nagoya City. The main attributes of this coverage are the grade of the road, its effective width, and the traffic flow. All roads are digitized as lines. (3) River coverage: This coverage can be especially useful in the bridge planning stage for deciding the width of the river, the highest water level, and the normal water level at the bridge location. The outlines and centerlines of the 27 rivers in Nagoya City are digitized, and the attributes are registered and made retrievable through the centerline coverage. The center and boundary of each river are digitized as lines and polygons, respectively. (4) Land use coverage: This coverage includes grid data of 10 meters mesh of Nagoya City. According to this coverage, the bridge engineer can investigate the conditions of land use around the bridge site. The land use coverage is digitized as a polygon coverage. (5) Soil coverage: All geotechnical data of soil data in Nagoya City are imported to the GIS system in the features of points representing boring points.
The main factors that effect the selection of the bridge foundations are the standard penetration test result (N-index) and the deformation coefficient. Fig. 2 shows the distribution of soil types in Nagoya City in 1:25000 district map. These soil types are classified for the purpose of seismic design according to the bridge seismic design specifications. With the development of this system, other boring data, which can be obtained from the construction of new structures and may be distributed in several associations, should be added to the 4190 available boring data at the present system.

(2) Design Information
At present, the design information includes the design drawing information such as the detailed design drawings, and numerical information such as the components’ dimensions, loads, resistance, and material properties from the design calculation reports. Bridge structural information after the design stage is usually managed in the forms of design drawings and calculation reports. One problem is the difficulty in manipulating this information by computers. A structural analysis is necessary for all existing bridges from the management point of view once the specifications are significantly changed. For instance, in the specifications of highway bridges, the truck load and the minimum concrete deck thickness are increased to 245 kN (25 tf) and 18 cm from 196 kN (20 tf) and 17 cm in the previous version of 1990, respectively. In addition, the structural analysis results by the forms of numbers, texts, and drawings, should be reserved in the database of the bridge lifecycle. However, the relational database that has been employed for many years can only process tables and numbers. In order to save and process design information, the database should possess the following functions: (1) Dealing with several kinds of information such as numeric values, texts, graphs, and images; (2) Providing the structural dimensions, material properties, and parameters that are used for both the detailed calculation and brief calculation; (3) Possessing data that can easily describe each of the main components of a bridge; and (4) Managing the history data, which present the structural changes of a bridge and are expected to be helpful for the present and future. In this research, an object-oriented DBMS is developed to satisfy the above requirements.

The object-oriented approach is adopted to develop the design database. Compared with the conventional relational database management system, the benefits of the object-oriented approach are its flexible structure and the usage of the abstract data type object. The object concept allows the representation of specific data (attributes) and abstract functions (methods) within similar objects. In addition, because inheritance among objects is possible, the common parts of the data and functions are defined in the super-class while the more specific data and functions are added to the sub-classes without the need to redefine the common attributes. The merits of using the object-oriented representation in the bridge management database are: (1) an object-oriented approach for the bridge management database makes it possible to include the bridge design data in the database and to integrate the data used in all the stages of the lifecycle of the bridge from the planning stage to the maintenance stage; and (2) using the object-oriented approach to represent the bridge structure enables the inspection and maintenance data to be periodically added as copies of the bridge objects.
Fig. 4 Main Attributes of Bridge Seismic Information Database

Fig. 3 shows an example of the object-oriented representation of the basic bridge data, and the inspection and maintenance data of the superstructure and substructure. In this research, C++ and Versant Library[20] are used to develop the system database. Versant has a C++ library for developing object-oriented databases.

(3) Image Information

Image information includes more than 5000 pictures of Nagoya City bridges. Images can be used to visualize the details of a bridge and to clarify the type of damages. Pictures are input to the database and made accessible through the image management system. The image data needed for bridge management contain the bridge general images and the images of the damaged parts. The role of bridge general images is to help in understanding the shape of the bridge in general. These image data are registered as attributes of the bridge object that can be retrieved. For instance, the image of the superstructure at the time of the inspection is added as an attribute to the inspection object and can be retrieved as a part of the inspection data. In order to grasp the position of the damaged parts and the relation to the whole bridge, many pictures are attached to the objects representing the members of the bridge in the object-oriented database. Retrieving the places of the damage starts by displaying the image focusing on the exact place of the damage. Then, a series of pictures are displayed in order to show the relative position of the damage in the whole bridge.

The images used in this research are scanned with an EPSON GT-8000 scanner and saved in TIFF (Tagged Image File Format). TIFF is adopted because it is more standard than other formats such as the SUN RASTER or the Macintosh PICT formats.

The images of all bridges are managed by an image database management system using the World-Wide Web (WWW). Bridges can be retrieved through the network from different platforms using a browser such as Netscape according to a number of keywords such as materials, road types, ages of bridges, traffic volume, bridge type, crossing type, rehabilitation history, and damaged conditions. By adding the keywords to each image, it is possible to link the images with other databases and use the images purposefully.

(4) Earthquake Information

The bridge earthquake management is becoming important from the viewpoints of research and application. However, it is difficult to implement at this stage because of the lack of seismic information. When an earthquake is considered at the design stage or a repair planning is worked out after a disaster, the effect of earthquake simulation is very important. If the earthquake information database is available, the necessary information can be used for simulation. The earthquake information is: earthquake damage information such as investigation reports on several previous earthquakes, seismic strengthening information, and damage image...
information such as pictures on damaged highway bridges after the 1995 Great Hanshin Earthquake. The collection and organization of these historical seismic data are very time-consuming because some of them are not well documented or not available in computer readable format. However, these data are helpful at several stages of the bridge lifecycle such as the seismic assessment of existing bridges and seismic strengthening plans.

At present, this research focuses on collecting and preparing the necessary data for seismic assessment of existing bridges and seismic strengthening plans. This information is managed by a database as the earthquake data, damaged bridges data, and seismic strengthening cases. This database is related to the above mentioned GIS and object-oriented databases. Fig. 4 shows the main attributes of this database. The main attributes are based on the common attributes in both the bridge inspection database and bridge seismic inspection database.

4. System Structure

The proposed system should fulfill the requirements of its users including government officials, who are responsible of managing the bridges, and young engineers and students, who need to understand the structure of the bridge. Fig. 5 shows the structure of the system. The different information discussed in the previous section are implemented in the main part of the system which has three modules: (1) GIS module, (2) object-oriented database module, and (3) image processing module. In the GIS module, spatial and statistical analyses are performed using a user-friendly interface. The object-oriented database module has the structural data of bridge. In addition, this module has the role of integrating the other modules. The image processing module handles images data and keywords data.

The previous modules are developed separately in order to facilitate the expandability of each of them. The graphical user-interface is responsible of communicating data among these modules in a transparent manner. The friendliness of the user interface is an important factor in increasing the effectiveness of the system. Although the main part of the system can handle all the data centrally, it is desirable to have access to the database from the different departments that are involved in the bridge management. With this respect, a subsystem has been developed using the WWW on the Internet. The WWW allows the use of hypermedia and hypertext where images can be imbedded within the text and linked to other files over the Internet. The manual development of these files is not easy, and it is possible to generate the necessary file on-line using programming techniques. In this system, the Common Gateway Interface (CGI) is used to facilitate the retrieval of information of the bridges including their images. For example, the user can retrieve bridges using a combination of keywords, or he can retrieve a series of images showing the location of the damage in a bridge member.

5. Examples of System Applications

(1) Example of Maintenance Planning Optimization

The optimal solution for bridge maintenance planning can have a significant positive economical impact. However, this kind of problem is extremely difficult
because a variety of factors influence the decision making. A bridge management system is a tool to assist bridge agencies in their choice of optimal maintenance plans of the network-level bridges in accordance with the agency’s policies, long term objectives and budgetary constraints. In order to select an optimal maintenance plan, several maintenance alternatives are available for each bridge or bridge component in the road network. The maintenance optimization has two principal functions: to estimate the maintenance needs of network-level bridges, and to calculate the maintenance cost. Taking one important bridge component, bridge deck, as an example, the maintenance plan of a network-level bridge system is optimized to minimize the maintenance cost of a given period of five years using a Genetic Algorithm. In this optimization approach, the system provides the basic data to predict the deterioration such as the initial conditions, yearly deterioration rates, and impacts of maintenance activities. This system also produces the parameters to the calculation of maintenance cost, which include the unit area cost of each maintenance method and the deck area of each bridge. Furthermore, this system possesses a good interface to represent the optimization results by showing the distribution of the bridges for each maintenance method at every year. Fig. 6 shows the maintenance method of each bridge deck of a maintenance plan at the second year. In this maintenance plan, the numbers of bridges with deck routine maintenance, repair, rehabilitation, and replacement are 173, 82, 30, and 2, respectively. City traffic planners can visually check the effects of the candidate maintenance plans on the traffic flow and choose the best maintenance plan.

(2) Example of Normal Management Application

Painting of steel bridges is a costly maintenance task that should be repeated every 5 to 10 years according to the conditions of the bridge. The system discussed in this paper can help in estimating the total painting cost at a specific year by using the history data of previous painting of each bridge and the dimensions data of all components.

(3) Example of Earthquake Management Application

The earthquake inspection data can be used in evaluating the safety of a bridge by assigning a numeric value to each inspection item, and summing up these values multiplied by weight factors that represent the importance of each item. The present system can help in evaluating the factors that are not considered directly in the inspection. For example, one damage case that has been observed in the Great Hanshin Earthquake is the falling of girders due of the lack of the seat width. However, the seat width has not been considered in the inspection before this earthquake. In such case, the present system can be used to retrieve the data related to the dimensions and positions of different elements to evaluate the safety of a bridge.

(4) Example of Data Visualization

In order to fully grasp the structure of a bridge, it is important to visualize the data of the bridge using 3D computer graphics. In this research, PHIGS library has been used to implement a simple graphical representation of the bridge elements. Fig. 7 shows an example of a bridge drawn by the system. At the present stage, only straight plate girder bridges have been implemented. In order to draw more detailed figures, it is necessary to link the system with a CAD software.

6. Conclusions

This paper can be concluded as follows:
1) By classifying the bridge lifecycle information into geographic, design, inspection and maintenance, earthquake, and image information, each type of information could be processed by the corresponding information technology efficiently.
2) Each information database can be separately retrieved and updated over time. The information on one stage in the lifecycle of a bridge can be efficiently utilized in its other stages or the lifecycle of another bridge.
3) The GIS module could integrate all kinds of geographical data influencing the bridge management and carry out spatial analyses on these data.
4) The object-oriented database approach was efficient in representing bridge design data. By attaching images, the bridge management issues were solved with visual assistance.

The system presented herein can be extended in several ways as follows: a) In the GIS module, it is necessary to anticipate the different situations that need spatial analysis and to develop procedures to help the bridge management planners, who may not be familiar with computers, in using the system efficiently. In the object-oriented database module, the method of representing the bridge
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design data needs further investigation. b) It has been widely recognized that the lifecycle analysis can play an important role in bridge management. The future development of this system can help in accumulating and managing the necessary parameters and data for the numerical calculations such as deterioration modeling and lifecycle analysis. c) Although the present system modules and applications were discussed in particular for network-level bridges, a similar approach can be applied for other civil infrastructure such as tunnels and roads. Further development is also required to integrate all civil infrastructures in a complicated system so that the decision-maker of a city can manage them in a more comprehensive manner.

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REFERENCES


