Current Trends of Information Technologies in Bridge Engineering

Y Itoh, Nagoya University, Japan
A Hammad, Nagoya University, Japan

ABSTRACT: Computers are used to assist bridge engineers at each stage of the bridge life-cycle including design, construction, and maintenance. In this paper, current trends of information technologies in bridge engineering in Japan are reviewed and future directions are discussed. Several information technologies, including object-oriented databases, GIS, expert systems, image processing, genetic algorithms, and so on, are adopted to increase productivity, improve quality, and manage the service life of bridges. The role of these technologies in satisfying new needs such as aesthetical and environmental requirements, as well as in integrating the processes involved in the bridge life-cycle are discussed.

1. INTRODUCTION

Civil engineers in general, and bridge engineers in particular, were pioneers in recognizing the potential of computers for processing the large volume of data needed at each stage of the life-cycle of structures. In the case of bridges, large volume of data is needed for bridge planning and design, fabrication and construction, service management and maintenance planning, and demolition and reconstruction. Several terms such as Computer-Aided Design (CAD), and Computer-Aided Engineering (CAE) were used to describe the gradually increasing involvement of computers in every-day work of engineers. This tendency evolved from the usage of databases to knowledge bases, from linear FEM analysis programs to non-linear FEM analysis packages with sophisticated pre- and post-processing modules, from 2D graphics to 3D graphics and virtual reality simulation, from probabilistic models to fuzzy logic models, and so on. This involvement became possible because of the advancement in computer science and information technology (IT), and the rapid development in computer hardware. The availability of cheaper and faster personal computers and engineering workstations with user-friendly interface and specialized softwares encouraged researchers and engineers to use these new tools.

In research, new techniques were adopted to handle problems of higher complexity such as Neural Networks (NN) for learning and pattern recognition, Geographic Information Systems (GIS) combined with remote sensing and image processing for creating and handling
spatial data, Genetic Algorithms (GA) for optimization purposes, and networking and multimedia for communication. As examples of these new approaches in Japan, Natsuuki et al. (1) proposed the application of GAs to the problem of determining the laying sequence for a continuous girder reinforced concrete floor system; Tsukada et al. (2) developed an assessment system for aesthetic design of bridges using image database and neural network; Iguchi et al. (3) explained the systematic maintenance management at the Hanshin Expressway Corporation in Japan; and Tanaka et al. (4) developed a system for refining a knowledge base concerning maintenance of fatigue damage in steel bridges. In spite of the active IT research in the field of bridge engineering, a lag continues to exist between research and practice. For instance, bridge companies in Japan have made good progress in automated bridge design, drawing, and fabrication systems. They efficiently used robotics and Numerically Controlled (NC) machines for labor intensive or dangerous work. However, they are conservative in applying new approaches of IT, mainly because of the lack of experience and the large budget needed for these approaches.

In this paper, some of the new approaches in bridge life-cycle CAE in Japan are demonstrated through several prototype systems, mainly developed by the authors. The methodology of each of these systems and their functions are discussed.

2. BRIDGE LIFE-CYCLE MULTIMEDIA DATABASE MANAGEMENT SYSTEM

Bridge management systems are widely used to facilitate the processing of bridge maintenance data. However, conventional relational databases can not manipulate the geographical data and image data effectively and have limitations in expressing the bridge structure and management data. Hammad et al. (5) developed a prototype database system that aims to overcome these limitations. The suggested system has three modules: (a) Geographic Information System (GIS) module, (b) object-oriented database module, and (c) image database module. Each of these modules is described briefly.

(a) GIS module: The geographical data that can affect the bridge such as of the soils, road network, and rivers' data are represented using independent coverages, and added to the database system so that spatial analysis can be done. By using GIS to integrate data, the following goals can be reached: (1) integrating the maintenance of all bridges within a specific area, (2) clarifying the mutual relation in the maintenance of a road network and the bridges within this network, and (3) visualizing the geographical data that may influence bridge management.

Figure 1 illustrates the data related to the bridge site represented by six types of coverages: contour lines coverage, road network coverage, rivers coverage, land use coverage, soil type coverages, and underground utilities coverages. In order to check the applicability of GIS in bridge life-cycle management, a case study including 287 bridges of Nagoya city in Japan has been carried out. Figure 2 shows an example of the geographical data that have been added to the system. In this figure, the data of the bridges, road network, rivers, and soils have been overlayed in one map.

(b) Object-oriented database module: The object-oriented representation of the bridge structure and maintenance data is investigated. The main items in the bridge maintenance database are: bridge inspection main data, superstructure and substructure inspection data, evaluation result data, and repair history data. Relational database management systems (DBMSs) are implemented by related tables and they can express only data that fit within the fixed table format. However, bridge inventory and inspection data have complex structure and are difficult to fit within this format. Therefore, the object-oriented DBMS approach is
used in this research to improve and expand the bridge management system. The benefits of the object-oriented DBMS compared with the conventional relational DBMS are its flexible structure and the usage of the abstract data type called object. Figure 3 shows a part of the bridge structure objects representation. Bridge data are represented by hierarchical objects that correspond to the structure of the bridge. In addition, the dimensions and the material of the bridge members and the related inspection and repair data are registered as attributes of the respective objects. By using the object-oriented representation in the bridge management database, the extensibility of the bridge DBMS to include design data becomes possible.

(c) Introducing static and dynamic image processing: In the present practice of bridge inspection, the detailed data related to the damage type 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 to later to help in the visual understanding of the damage pattern and damage place. In this research, static and dynamic images are added to the bridge management database system. Keywords explaining the characteristics of each image are added. These image data are registered as attributes of the bridge objects. On the other hand, dynamic image data need a huge memory when saved in digital form. Therefore, in the case of long video scene, the VCR tape is controlled by the computer.
Figure 4. Flowcharts of (a) Road Alignment Selection Procedure and (b) Bridge Type Selection Expert System

Figure 5. Relationships between Span Length, and Energy Consumption and $CO_2$ Emission
3. BRIDGE LOCATION SELECTION AND TYPE SELECTION

USING GIS AND EXPERT SYSTEM

In the planning process of a new road network, the planner should consider possible locations of bridges and tunnels. The selection of the best alignment of the road network is difficult because of the variety of factors involved in the decision making and the complex interaction between these factors. The selection of the bridge site influences the choice of the bridge type and vice-versa. For instance, the construction cost of bridge piers at a given crossing may greatly affect the number and lengths of spans, which in turn affect the cost of the superstructure and thus the total cost of construction. Hammad et al. (6) suggested combining GIS and expert system techniques to evaluate the bridge types at different locations, and to use the result of the evaluation in the evaluation of the whole road network. In the developed prototype system, the GIS database is used as a repository database for the road network design. The flowcharts of the road alignment selection and bridge type selection are shown in Figures 4(a) and (b). The road planner can start by trying a road alignment interactively using the GIS. The bridge locations along the road are found and the cross section of the river at a bridge site and other characteristics of the site are extracted from the computerized map using the spatial analysis capability of the GIS. For each candidate site, the type of the bridge superstructure and substructure are selected using expert system techniques. The expert system, developed by Nishido et al. (7) selects the span arrangements and generates all the possible bridge type combinations. Each solution is evaluated by calculating its construction cost. In addition, a total assessment based on easiness of erection, maintenance, driving comfort and landscape is done and the best three bridge types for the specific location are found. Evaluating the landscape of bridges quantitatively has been considered to be very difficult since it involves many subjective factors. In this system, landscape evaluation is done by assigning points to each bridge type according to the bridge type itself and its harmony with the environment (8). The results of the expert system are used in the GIS system, and their effect is considered in the total evaluation of the road. This process is repeated several times until the final road alignment is decided.

Recently, there is a world-wide interest in environmental problems, especially in developing countries where rapid economic growth is expected. Therefore, the expert system for bridge type selection is further developed for considering the environmental impact of the bridge and other technology transfer requirements. The environmental impact of each candidate bridge type is evaluated by the volume of energy consumed and CO$_2$ emission from the material and erection equipment. In addition, the effect of recycling construction materials is also considered. Figures 5(a) and (b) show the relationships between span length and energy consumption and CO$_2$ emission, respectively. It is clear from these figures that steel bridges consume more energy than PC bridges of the same span length because of the high amount of energy needed for steel fabrication.

4. AUTOMATED BRIDGE DESIGN AND DRAWING SYSTEMS

Box and I-plate girder bridges are used in highway construction especially in metropolitan areas. Several automatic design and manufacturing systems have been developed by Japanese bridge fabricators since the 70's. Some of these systems are called total systems because the system can generate the design data, do the structural analysis, draw the profile and the cross sections of the bridge, and create the data for the NC machines (9). Recently, similar systems have been developed for other type of bridges that are comparatively more difficult
Figure 6. Automatic Drawing of Box Girder Bridge Cross Section (10)

Figure 7. Example of the Bridge Profiles of the Original Design and the Re-designs:
(a) Bending Moment Graphs of the Original Design; (b) The Original Design;
(c) Case 1; (d) Case 2; (e) Case 3
to standardize. Nagasaki et al. (10) developed an automated design and drawing system for box girder bridge with steel plate deck. Figure 6 shows an example of a bridge cross section drawing produced by this system.

5. IMPROVING THE DESIGN OF BRIDGES BY USING DESIGN KNOWLEDGE BASE

Until recently, the cost of steel bridges was generally estimated in Japan using the price per unit weight. Therefore, bridge designers and fabricators were required to decrease the steel weight of the bridge. This resulted in increasing the number of cross section variations and the number of weld lines. However, because of the shortage of technicians and increase in labor cost, it was necessary to consider the possibilities of simplifying and accelerating the fabrication process in order to get more rational and near optimal design. Knowledge-based systems, when combined with actual design data of available bridges, can support the decision making process for improving both design and fabrication. Hammad et al. (11) discussed the creation of a knowledge base that includes data on previously designed plate girder bridges, and its application in considering the effects on the cost of the bridge of simplifying the design. The knowledge base is used to investigate several design alternatives by selecting and re-designing some bridges from the knowledge base. Several suggestions for a more rational design are given, based on previous design information.

Figure 7 shows an example of the re-design cases for a three spans bridge. Figure 7(a) shows the graphs of the bending moment envelope and the resisting bending moment of the original design shown in Figure 7(b). In this case, the cross section changes at many points following the bending moment envelope. In the re-design cases, the following simplifications are done: Case 1: To make the cross section changes only at the joints' position; Case 2: To reduce the number of vertical stiffeners and horizontal stiffeners; and Case 3: A combination of Case 1 and Case 2. These three cases are shown in Figures 7(c), (d) and (e), respectively.

6. STEEL BRIDGE SHOP ASSEMBLY SIMULATION

In Japan, steel bridges have to be inspected before the final assembly by the client, usually a public authority, in order to check the dimensions of the bridge. For this purpose, until recently, a bridge has to be temporarily assembled and then disassembled in the yard of the fabricating company. This process is costly and time consuming. Several systems have been developed that can simulate the assembly of I-plate girder bridges (12, 13).

The system described in (12) simulates the shop assembly by first measuring the dimensions of members and position of bolts' wholes, and then inspecting the final assembled bridge. Figure 8 shows the configuration of the bridge assembly simulation system. Several CCD cameras are used to take pictures of the bridge member. These pictures are then analyzed using image processing techniques.

7. NETWORK-LEVEL BRIDGE MAINTENANCE OPTIMIZATION USING GA

With the rapidly increasing requirements of bridge maintenance and the limited budget available for this maintenance, the cost optimization of long-term maintenance strategy considering the network-level bridge system under an allowable deterioration level is becoming an important problem. However, the total maintenance cost is a function of the number of bridges and their deterioration degrees, the planning period, and the maintenance methods. Liu et al. (14) suggested using a genetic algorithm for optimizing the deck maintenance cost of a network-level bridge system. In this research, a population of maintenance strategies
Figure 8. Configuration of the Bridge Assembly Simulation System (12)

Figure 9. Example of GA Maintenance Optimization Sensitivity Analysis

Figure 10. Example of Test Results and Design Curves
evolves from one generation to the next by applying selection, cross-over, and mutation operators. A sensitivity analysis is done to check the effects of the population size, the crossover probability, and the mutation probability $P_m$. It is found that moderate population size (50), high crossover probability (80%), and low mutation probability (0.1%) are good for this GA performance considering the convergence requirement and calculation time. Figure 9 shows an example of the convergence for several values of the mutation probability.

8. INFORMATION ENVIRONMENT FOR STRUCTURAL TESTS DATA
AND NUMERICAL ANALYSES

Recently, in order to grasp the static and dynamic behavior of bridges, many kinds of tests and FEM analyses have been undertaken. The huge amount of numerical data resulting from these tests and analyses are available in the computer-readable format. However, it is difficult to use test data in their raw format and many steps of processing are necessary in order to get the useful value of these data. On the other hand, the best method of conformance checking of nonlinear FEM programs is to use bench-mark tests and to compare the results of one program with other programs and with the results of the structural tests. Itoh et al. (15) developed a multimedia object-oriented information environment for structural tests data and numerical analyses results. The system has three main targets: (a) To provide an integrated framework for organizing, distributing, retrieving, and comparing structural tests data and numerical analyses data. These data are necessary to establish and update standard design curves used in design codes. Figures 10 and 11 show examples of comparing test data with design curves and analysis data, respectively; (b) To create an environment for facilitating the code-less design approach by providing data similar to the European Calibration Frames; and (c) To organize and accumulate the relatively scarce data related to seismic testing and analysis such as pseudodynamic tests. Figure 12 shows an example of pseudodynamic test results retrieved from the system.

Figure 11. Comparing Test and Analysis Data

Figure 12. Example of Pseudodynamic Test Results
9. CONCLUDING REMARKS

As in other engineering fields, bridge engineering is heavily depending on information technology (IT). The rapid progress in IT continues to promise increasing benefits for bridge engineers. In addition to the specific benefits of using special IT techniques for solving local problems, the following general benefits can be stated as short-term targets to be achieved: (1) Integration and information-sharing on the bridge level: This is realized by integrating the data of all stages of the life-cycle in one distributed system. This integration of planning information, design information, and maintenance information will benefit all the engineering and managerial parties involved in bridge engineering. Object-oriented databases start to be practical tools for this integration. (2) Integration and information-sharing on the road network level: This integration is multi-disciplinary spanning bridges, roads, and other infrastructure. GIS technology has the potential to play a major role in this integration. (3) Accumulating knowledge necessary to solve new problems: Although expert systems could not fully satisfy the high expectations of engineers so far, it is still feasible and practical to use these systems to handle difficult problems such as landscape evaluation. Knowledge acquisition and updating for these systems should be given the due importance. (4) Efficient application of networking and multimedia technology: These technologies should provide better connectivity among the people involved in the bridge life-cycle management.

References