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New Approach toward Bridge Management Database Systems

Nouvelle approche pour les systèmes de base de données des ponts

Ein neuer Ansatz für Brückendatenbankmanagementsysteme

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SUMMARY
Conventional bridge management database systems have many limitations in expressing bridge components, historical and geographical data of the bridge environment, and in integrating image information. A prototype bridge database system using new information technology is proposed to overcome these limitations. An object-oriented Geographic Information System database, and image and video processing are introduced to the bridge management database system. These improvements make it possible to use the system during the whole life cycle of the bridge, from the planning stage to the maintenance stage.

RÉSUMÉ
Les systèmes conventionnels de bases de données pour la maintenance des ponts sont limités quant à la description des éléments des ponts, leur histoire, leurs données géographiques de l'environnement du pont, de même qu'à l'intégration de l'information des images. Une base de données utilisant de nouvelles technologies informatiques est proposée pour surmonter ces obstacles. Un système d'information géographique, à base de données orientée-objet, et un traitement des images par la vidéo sont introduites dans le système. Les améliorations devraient permettre l'utilisation du système proposé pendant tout le cycle de la vie des ponts, de la conception à l'exploitation.

ZUSAMMENFASSUNG
Konventionelle Brückendatenbankmanagementsysteme sind sehr beschränkt bezüglich der Erläuterung des Brückenaufbaus, den historischen Daten sowie der geographischen Daten der Brückenumgebung. Es wird ein Prototyp eines Brückendatenbanksystems vorgeschlagen, der eine neue Informationstechnologie verwendet, um diese Einschränkungen zu überwinden. Ein geographisches Informationssystem, eine objektorientierte Datenbank sowie Bild- und Videoverarbeitung werden in das Brückendatenbankmanagementsystem eingeführt. Aufgrund dieser Verbesserungen sollte es möglich sein, dieses System während des gesamten Lebenszeitraums der Brücke, vom Planungsstadium bis hin zur Instandhaltung, zu verwenden.

1. INTRODUCTION

Because of the lack of maintenance of the infrastructures in the U.S.A., these structures are undergoing rapid deterioration. This is specially true for bridges where 20% of the total number of bridges are needing major repair. It is thought that the main reason for this problem is the shortage in the public capital invested in bridge maintenance during the last three decades [2]. In contrast with the U.S.A., the public capital investments for roads and bridges in Japan are still used in new construction works and less budget is allocated for maintenance. However, the large number of structures that have been built during the economic growth in Japan are getting old. Therefore, budget needed for repairing and renewing these structures should be increased.

Based on this background, there have been some trials to improve bridge maintenance by developing databases that facilitate the processing of bridge maintenance data. However, conventional relational databases can not process the geographical data and image data effectively and have limitations in expressing the bridge structure and management data. In this research, a prototype database system is developed that aims to overcome these limitations. This system uses new information technologies and represents a new type of bridge management information systems.

2. THE STRUCTURE OF THE SYSTEM

The suggested prototype database system has three modules: Geographic Information System (GIS) [6] module, object-oriented database module, and static and dynamic image processing module. Fig. 1 shows the structure of the system. In the following paragraphs, the data used in each module are explained.

1. Geographical data:

   The geographical data that can effect the bridge such as of the soils, road network, and rivers' data are added to the database system so that spatial analysis can be done using these data. The information of location and shape are represented using independent coverages. ARC/INFO (Environmental Systems Research Institute, Inc.), a workstation-based GIS, is used for the development of the system [3].

2. Bridge structure and maintenance data:

   The object-oriented representation of the bridge structure and maintenance data in the database is investigated. At the time being, this module has only the basic functions of the database system such as creating, deleting and retrieving objects. The bridge objects database can be used independently or it can be accessed through the bridge coverage of the GIS module.

3. Static and dynamic image data:

   Static and dynamic images can be used to visualize the details of the bridge and to clarify the type of damages. Pictures and video recording are input to the database and made accessible through the static and dynamic image processing module. The images related to each object of the bridge are added as attributes of this 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.

It may be possible to use the previous data during the whole bridge life cycle from the planning stage to the management stage. In the rest of this paper, each of the three modules of the system will be discussed in detail.

3. GIS-BASED BRIDGE MANAGEMENT SYSTEM

3.1 Merits of Using GIS for Bridge Management

Recently, many researches have been made about the applications of GIS in planning. In the field of bridge planning, a research has been carried out about the effective use of GIS for bridge planning

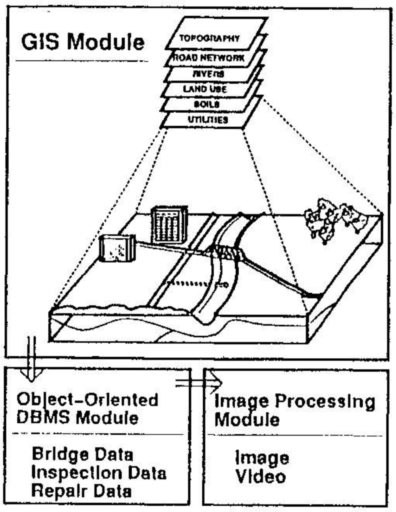


Fig.1 System structure

[5]. GIS software offers spatial analysis and statistical analysis capabilities by integrating graphic processing and database functionalities with a powerful user interface. 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 by numbers and character strings that form a database.

In this research, the geographical factors that can effect the bridge structure during its life cycle such as the soils, road network, and rivers'data are represented by independent coverages. These coverages can be overlayed and intersected in the process of spatial analysis. This paper discusses only the usage of the GIS coverages for maintenance purposes. However, it is believed that the same coverages can be useful for the life cycle bridge management because they include a variety of data that is necessary for bridge planning, maintenance, and management in general. By following this integration, the following goals can be reached:

1. Integrating the maintenance of all the bridges within a specific area.
2. Clarifying the mutual relation in the maintenance of a road and the bridge (or bridges) within this road.
3. Visualizing the geographical data that may influence bridge management.

In order to check the applicability of GIS in bridge management, a case study including 50 bridges of Nagoya city in Japan has been carried out. The data of the bridge inventory and other data needed for the bridge management are input to the system. The selected bridges are steel and concrete girder bridges. The range of bridge lengthes is between 10 m and 500 m, and the construction year is between 1931 and 1990.

Fig. shows an example of the geographical data that have been added to the system. The data of the bridges, road network, rivers, soils, etc. have been overlayed in one map. This kind of representation allows linking location's data and features' data in the coverages, and therefor, it allows matching several coverages in a way that is useful for bridge management. A menu-driven interactive user interface for data retrieval and spatial analysis has been developed with the programming language of ARC/INFO.

3.2 Data Collection and Pre-Processing

The main geographical data coverages considered in this research are: bridges coverage, road network coverage, rivers coverage, and soils coverage. In the following paragraphes, each of these coverages is discussed briefly.

1. Bridges coverage: This coverage contains the location and the main dimensions of the bridges such as the length and the width. 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 the national roads, the expressways, and the other main roads in Nagoya city. The main attributes of this coverage are the grade of the road, its effective width, and the amount of its traffic flow.

3. Rivers coverage: This coverage can be especially useful in the bridge planning stage for deciding the width of the river, the high water level, and the flood level at the bridge location. The outline and the centerline of the 14 rivers in Nagoya city are digitized, and the attributes are registered and made retrievable through the centerline coverage.

4. Soils coverage: All the data of *New Nagoya Soils Database* [4] are imported to the GIS system. The data include the information of 4190 borings. The main factors that effect the selection of the bridge foundations are the standard penetration test result (N-value) and the deformation coefficient E. GIS can represent coverages in 2 dimensions only. Therefore, in order to represent the third dimension of the soils data, the depth information are added in a manner that allows the retrieval of the soil strength at the foundation depth. For instance, in the planning stage of a new bridge, the boring data near the potential location of the bridge can be used in the preliminary design of the foundation. Fig. 3 shows the boring locations near the rivers in Nagoya city. This retrieval is done by first creating a 200 m wide buffer around the centerline of the rivers, and then intersecting this buffer with the coverage of the boring locations.

   The original data of Nagoya soils database are divided into a mesh of about 100 m step. The boring data within a 140 m $\times$ 115 m square area in the mesh represent the whole of this area. Therefore, the data retrieved from the database in the planning stage may be up to 100 m far from the real location, and it is necessary to use engineering judgment when using these data. Figs. 4(a) and 4(b) show the comparison between the soil database and the inspection data from the bridge inventory at two points A and B. The solid line shows the soil data from the database while the dotted line shows the real inspection data. In the case of point A, the data of the database are very near to those of the inspection. However, in the case of point B there is some difference which means that the data of the boring database should be used as an approximate pointer about the soil type. The degree of the approximation depends on the number and the distribution of the boring points, i.e. if the boring data show that changes in the soil properties are small over a sufficiently wide area around the point under consideration, then the data of the soil at this point can be reliably used.

3.3 Examples of Spatial Analysis Using GIS

Two examples are given to show the advantages of using GIS within the bridge management system.

1. GIS can be used to clarify the relationship between the road and the bridge. For this purpose, the proposed system makes it possible to retrieve all the bridges in the same road or crossing the same river, or that satisfy other combinations of spatial conditions. For instance, retrieving all the bridges in a specific region with high traffic flow and that have not been repaired yet. Fig. 5 shows the result of the previous retrieval. In this example, the bridges within the specific region are retrieved first, then the bridges with traffic flow more than 10,000 cars/12h and with no repair are selected from them.

2. In the case of a disaster or during the repair of a river-crossing bridge, this bridge goes out of function and there should be alternative bridges to be used to cross the river instead of the

Fig.2 The different geographical data

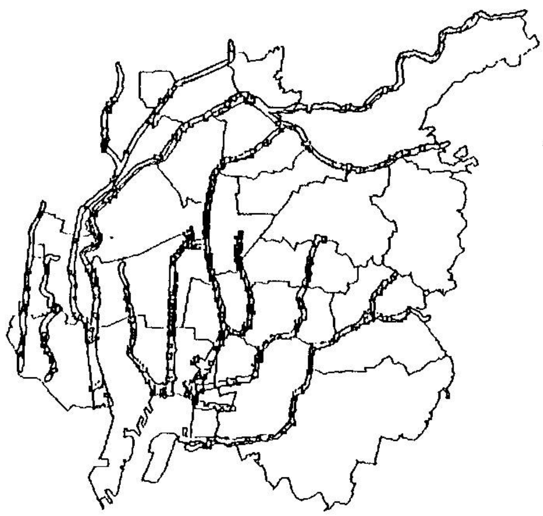


Fig.3 Boring points near the rivers

damaged bridge. These bridges should be near the bridge in question and should be able to resist the same design load. By retrieving the bridges that satisfy these conditions, it is possible to find alternative routes during the closing of the bridge. Fig. 6 shows an example of this case with a buffer of 1km around the bridges.

These examples show that complicated spatial retrievals can be done for items that are not explicitly defined in the bridge management system by overlaying several coverages. To be able to do the same retrieval in conventional bridge management systems, all the related attributes should be predefined in the database. Using GIS allows for doing spatial analysis, integrating the different data, and visualizing the results of the analysis.

4. OBJECT-ORIENTED DESCRIPTION OF BRIDGE INFORMATION

In the previous sub-section, the benefits of using GIS for representing the bridge-related geographical information have been discussed. In this sub-section, the representation method of the bridge data itself is discussed.

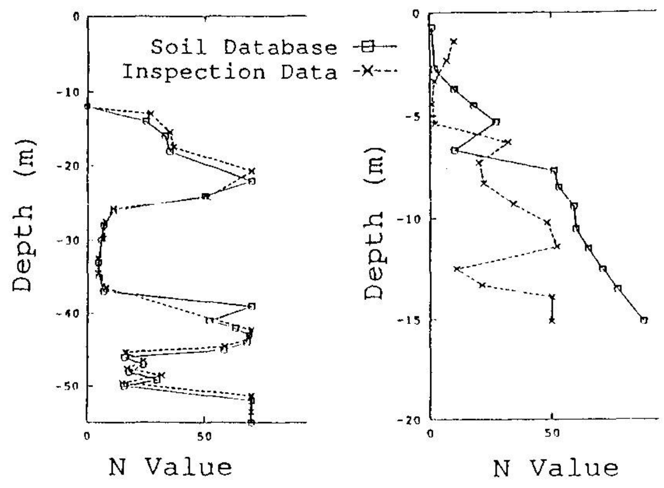
In 1991, in order to evaluate the state of the bridges in Japan and to provide the materials necessary to rationalize bridge maintenance, the Japanese Ministry of Construction ordered the local authorities to inspect the bridges within their areas. In this occasion, a new bridge management database system has been developed aiming to facilitate the exchange of data between the planning departments and to the higher authorities. This system is adopted as a model all over Japan [1]. The main items in the database are:

1. Bridge Inspection Main Data:

   These data contain the items usually found in the bridge inventory database such as bridge length, bridge width, type of foundation, bridge location, construction date, traffic flow, etc.

2. Superstructure Inspection Data:

   The existence of damage in the members of each span of the bridge according to the type and the material of the members are registered within these data. The name of the member and the counter-measures against the damage are also registered. The information related to the span number, the member name, and the type of damage are added by their code values. These data are used in the evaluation of the necessity of reapir.



(a) Point A (b) Point B

Fig.4 Comparison of standard penetration test values

3. Sub-Structure Inspection Data:

   The data of the sub-structure are similar to those of the superstructure.

4. Evaluation Result Data:

   This part has the result of the evaluation of inspection data and the necessity for repair for each member in the super- and sub-structure.

5. Repair History Data:

   Repair history data include the year and the method of the repair, the cost of the repair, etc. Fig. 7 shows the repair years of the 50 bridges used in the case study of this research. The figure shows that 20 bridges only have been repaired and that some of these bridges have been repaired more than one time. The repair method is given by its code and special repair cases are described briefly by a character string comment. Most of the repair cases are because of structural deficiencies of the bridge.

This database system is implemented on a personal computer using the relational database management system (DBMS) dBASE-III. Relational DBMSs are expressed by related tables and they can express only data that fit within the fixed table format. However, bridge inventory data and bridge inspection data are complicated and are difficult to fit within the relational DBMS. For instance, the items used in the bridge inspection may differ depending on the type and the material of the bridge. These items may differ even for the same bridge type when the number of spans changes. In order to overcome these problems, 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. The object concept allows the representation of specific data (members) and abstract functions (methods) within similar objects. In addition, *inheritance* among objects is possible, i.e. 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 $C++$ language is used for the implementation of the prototype [7].

Fig. 8 shows a part of the bridge structure object representation. This figure will be used also to compare the object-oriented DBMS and the relational DBMS, and to explain the merits of the former approach. In the relational bridge DBMS suggested by the Japanese Ministry of Construction, the

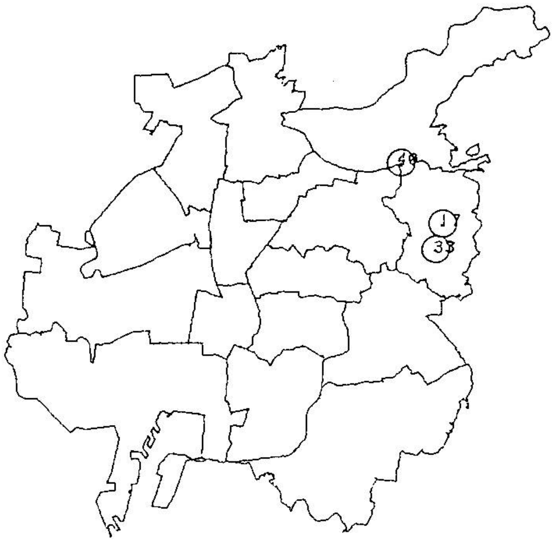


Fig.5 Retrieving bridges for maintenance

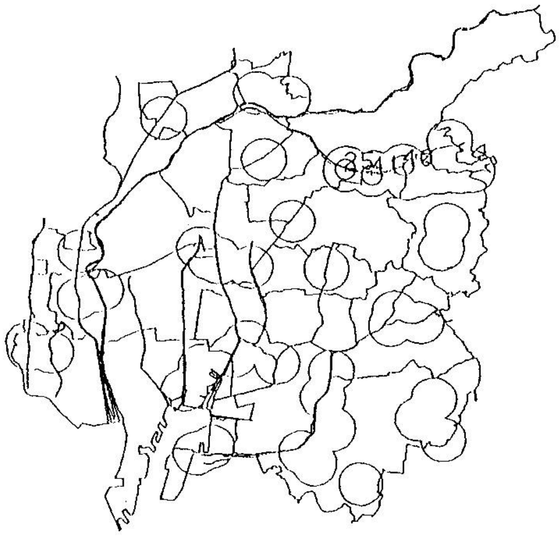


Fig.6 Retrieving alternative bridges

data of the bridge are represented by 5 tables (relations). With this respect, in the object-oriented bridge DBMS suggested in this research, the same data are represented by hierarchical objects that correspond to the structure of the bridge structure. 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. Fig. 8 shows the object-oriented representation of the basic bridge data and superstructure and substructure inspection and repair data. The merits of using the object-oriented representation in the bridge management database are:

1. The extensibility of the bridge DBMS:

   The object-oriented representation of the bridge management database facilitates the management of the data. Consequently, including the bridge design data in the database (which is difficult with conventional database models) becomes possible and these data can be used to integrate the data used in all the stages of the life cycle of the bridge from the planning stage to the maintenance stage.

2. Emphasizing the bridge history data:

   In the bridge DBMS suggested by the Japanese Ministry of Construction, the time-dependent data of the inspection and repair history are registered first, and the names of the parts of inspection or repair are added, e.g. superstructure at span number 3. However, in the relational bridge DBMS, it is difficult to specify the exact place of damage, e.g. the upper flange of member 2 in girder 1. However, using the object-oriented approach to represent the bridge structure makes it possible to add the inspection and repair data periodically to the copies of the bridge objects. For instance, in case there is a repair work in the upper flange of the second member of the first girder, the details of the repair can be registered in an instance of the corresponding object.

5. INTRODUCING STATIC AND DYNAMIC IMAGE PROCESSING

In the present practice of bridge inspection, the detailed data related to the damage type in the bridge members 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

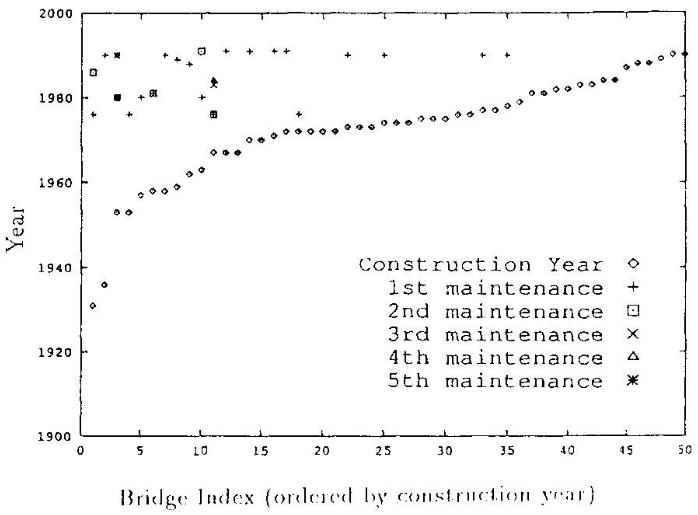


Fig.7 Repair years of the bridges

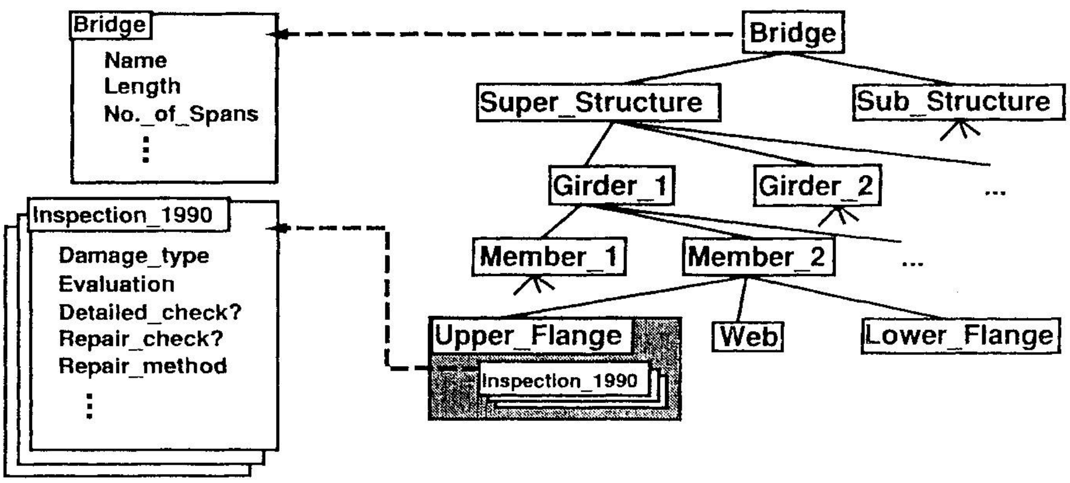


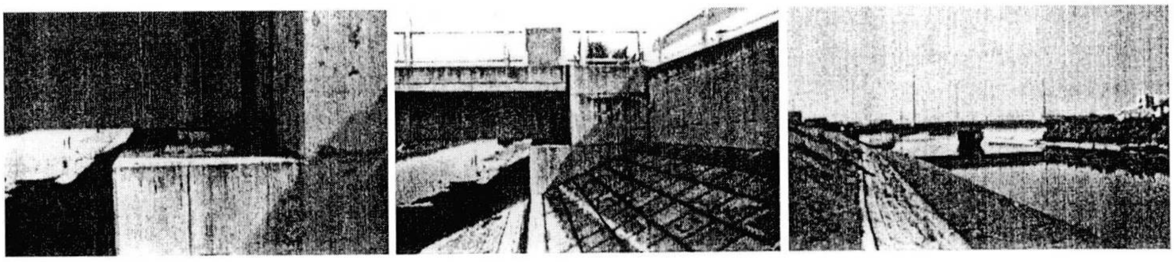
Fig.8 Example of the object-oriented representation of the bridge

later to help in the visual understanding of the damage pattern and damage place. The conventional bridge DBMS can usually handle only numbers and character strings and therefor, image data can be accessed only through an index corresponding to the file containing the image.

However, 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, combining graphics, character data, static and dynamic images, and sound data in an integrated multimedia environment that can appeal to the different human senses is becoming popular. For instance, in the field of civil engineering, images are introduced to road inspection system [8]. In this research, the application of new media such as static and dynamic images in the bridge management system is suggested.

1. Static image data: The static image data that are necessary for bridge management are:

   (a) Bridge general images: The role of these images is to help understanding the shape of the bridge in general. In this research, 3 images are scanned and saved for each bridge (profile image, image from the bottom, and image of the support). A comment explaining the



(a) Place of the Damage (b) Part of the Bridge (c) Total View of the Bridge

Fig.9 Example of retrieving the damaged place

characteristics of each image is added. These image data are registered as attributes of the bridge object.

(b) Images of the damaged parts: In order to grasp the place of the damaged parts and its relation to the whole bridge, many pictures showing gradually smaller scope are attached to the objects representing the members of the bridge in the object-oriented bridge DBMS. In addition, it is made possible to compare the images of the damage part before and after the damage. 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 number of the images in one series is not fixed but 3 to 5 images would be usually enough. Fig. 9 shows a series of images showing the place of the damage in the abutment under the right support of the bridge.

Because image data usually need huge storage memory, it is necessary to decide the specifications concerning the quality of the image and its format so that these images can be accumulated and managed in the most economic and efficient manner. The images used in this research are scanned with an EPSON-GT8000 scanner and saved in TIFF format (Tagged Image File Format). TIFF format is adopted because it is more standard than other formats such as the SUN RASTER or the Macintosh PICT formats.

2. Dynamic image data: Using dynamic images, it becomes possible to visually record the steps used in the maintenance and repair in the shape of a short movie that can be replayed. However, dynamic image data need a huge memory when saved in the digital form on the harddisk, which is expensive. Therefore, in this research, two methods are proposed for processing dynamic image data.

   (a) Only the dynamic images of the damaged parts are saved in the digital form. A Macintosh Centris-660AV is used for inputing the images and they are saved in MPEG (Motion Picture Experts Group) format. The reason for chosing MPEG format is that it is more widely used standard than other formats and it has an efficient compression algorithm. Table 1 shows a summary of the methods used in manipulating static and dynamic images.

   (b) In the case of long video scene, the VCR tape is controlled by the computer. The video control device SONY Vbox-CI-1100 is connected to the computer with an RS-232C interface, and connected to the VCR (SONY SLV-RS7) with a LANC interface. The main functions of controlling the VCR are: play, rewind and forward, and search for a specific scene using the real time counter. This method of keeping the video data in its analog form is more economic than the digital video. However, the access time is long due to the sequential nature of the video tape.

	Static Images	Dynamic Images
Image Quality	100 dpi	20 frame/sec
No. of Colors	256	256
Size (pixel)	320 × 240	160 × 120
File Size	about 100 KB/image	about 6 MB/min
Format	TIFF	MPEG
Input Device	EPSON-GT8000	Centris-660AV
Saving Device	HD	VCR, MO, HD

Table 1 Summary of the methods used in manipulating images

6. CONCLUSIONS

Bridge management databases are becoming more widely used in the practical level. The new methodology presented in this paper to represent and process the bridge-related data is still in the first stage of application. However, it is expected that applying this methodology in future bridge management systems can give better results than the conventional bridge management databases in integrating the different data in one system. Such a system can be used for the life cycle management of all the bridges on the network level. The main conclusions of this paper are:

1. Using GIS within the bridge management system helps in integrating the geographical data that may influence the bridge maintenance process and in carrying out spatial analysis on this data, which is not possible in the conventional bridge management systems.
2. The object-oriented database approach proves to be efficient in representing bridge inventory data and bridge inspection and repair data.
3. The multimedia approach resulting of adding static and dynamic images is useful in the visual understanding of bridge management problems.

Some of the problems that have been faced in developing the proposed prototype system are:

1. 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.
2. In the object-oriented database module, the method of representing the bridge design data needs further investigation.
3. Several problems remained to be solved about the efficient method for retrieving and comparing image data such as deciding the camera location for taking pictures, etc.

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