DATABASE FOR STRUCTURAL STEEL EXPERIMENTS UNDER A DISTRIBUTED COLLABORATION ENVIRONMENT

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ABSTRACT

Due to the high requirements of civil infrastructures against the earthquake in Japan, a great number of research organizations have been conducting the structural steel experiments, in particular the seismic tests such as the cyclic loading test and the pseudo-dynamic test, for many years to determine the seismic performances of steel structures. However, the original test data gained by most research organizations are not well stored in an appropriate manner for distribution and possible usage of others. Although a Numerical Database of Steel Structures (NDSS) was developed some years ago to preserve and share experimental data of the ultimate strength tests acquired at Nagoya University, it was not easy to access this database from other computer platform due to the lack of the support of proper communication media. With the rapid development of information networks and their browsers, structural engineers and researchers are able to exchange various types of test data through Internet. This paper presents the development of a distributed collaborative database system for structural steel experiments. The database is made available on the World-Wide Web, and the Java language enables the interactive retrieval efficiently. The applications of the developed database system for the retrieval of experimental data and seismic numerical analysis are validated in the form of examples.

INTRODUCTION

Since the Great Hanshin Earthquake in 1995, the Japanese engineers and researchers in civil engineering have had an increasing social pressure and professional responsibility to improve the behaviors of civil infrastructures against the natural disasters (Kawashima 2001, JSCE 2000). The seismic tests such as the cyclic loading test and the pseudo-dynamic test have been conducted in many research organizations to determine the seismic performances of steel structures. However, only a part of data on these tests have been published as reports or papers, and most of them such as dimensions and failure types of specimens have not been published. The original test data gained by most research organizations are not well stored in an appropriate manner for distribution and possible usage of others. In order to preserve and share experimental data, a Numerical Database of Steel Structures (NDSS) has been developed at Nagoya University since the 1980s (Itoh 1984, Itoh et al. 1996, Itoh et al. 2002). This database has been referred as the basic data for the revision of various specifications on steel structures all over the world. However, taking into account of the access from the outside of the university, this database is not efficient from the viewpoints of both hardware and software although efforts were carried out to utilize the information technology and knowledge approach to strength the original database.

With the rapid development of information network technologies of Internet, these technologies have been applied in the research, engineering practice and education. For example, by taking the advantages of the Internet, a distributed database system for the network-level bridge management was developed for the purposes of retrieving network-level bridge information, collecting and exchanging information, visualizing the bridge condition, and so on (Itoh et al. 1996). A prototype infrastructure modeling system was designed and developed to help decision makers to manage the coastal infrastructure based on the Internet (Wallace et al. 2001). A Java-based environmental regulation broker was designed to help users in locating relevant environmental regulations over the Internet (Liang and Garret 2000). The recent growth of Internet application has mainly been due to the establishment of the World-Wide Web (WWW) and the related development of browsers such as Mosaic, Netscape, and Internet Explorer. The WWW has become an unavoidable tool like the telephone, fax machine, and computer itself, and has provided fresh opportunities for the researchers and engineers in civil engineering to utilize the structural steel experimental data more efficiently.

In this research, a distributed collaborative database system for structural steel experiments that includes the valuable data of seismic test results and the ultimate strength test results relating to strength and ductility has been developed to collect and combine various types of test data including the numerical data, text data, images and videos. The data in the above-mentioned existing database have also been made available on Internet using the Java. This new database is useful for the purposes of study and education in civil engineering as well as research. Furthermore, a distributed collaboration system is developed for the structural steel experiments in the form of a metadata server and collaborative databases administered in various servers through the Internet so that the user is able to retrieve the test databases stored at distance servers of various organizations by accessing the central metadata server. Finally, this paper concisely reports the progress of an undergoing research project on the database development for performance-based design and analysis of bridge guard fences.

DESIGN OF A DATABASE FOR STRUCTURAL STEEL EXPERIMENTS

Background

The Internet is literally growing because of its interaction with human behavior and habits (Seneviratne et al. 1999). It is not just a dynamic network medium, but a quickly growing communication infrastructure. The Internet provides structural engineers and researchers a unique opportunity to expand their experimental data into the cyberspace. On the other hand, no matter an expert in civil engineering or an undergraduate student can access the proposed database through the World-Wide Web from various types of computer platforms such as Macintosh, Windows and Solaris for the purposes of learning, reference, downloading data, or providing information. The proposed database system contains the client and server sides as well as the WWW. With the user interface designed using the HyperText Markup Language (HTML) program and Java program, the database storing the structural steel experimental data can be accessed in the forms of photos and digitized information in addition to the numerical and text data, which is enriched by the Internet technologies.

The potentials to develop a web-based collaborative database for structural steel experiments are derived from capacities of the Internet, including: (1) Communication Technology: It is easy, rapid, and inexpensive for structural engineers to connect to the Internet using the common computer without the support of any commercial software; (2) User Interface: The WWW browser involves and excites users so that few users had to attend a browser class or read a manual on a browser in order to be able to access a WWW page by pointing and clicking on a highlighted object; (3) Multimedia Data: The Internet enriches the documentation in the forms of photos and digitized information in addition to the numerical and text data; (4) Search Engines: The availability of WWW with automated text search engines is one important technical development, by which the structural engineers can discover the locations of the attainable databases quickly, efficiently, and accurately; and (5) Vast and Constantly Updated Information: Vast information in the Internet can be updated and accessed constantly in different computer platforms. The engineers or researchers who carried out the experiment can present their idea, concept, and strategy of a specific experiment in the Internet, and can make them available to be downloaded easily and for free.

Users including learners such as students and novice structural engineers are linked with the database under the support of the Internet. In Japan, the design methodology is being shifted to the performance-based design in these years. For example, in the latest version of Specifications of Highway Bridges published in 2000, the performance-based design is partially applied and will be further utilized in the next version to be published in the following five to 10 years (JRA 2000). Furthermore, the performance-based design methodology will be used completely in the Design Specifications of Concrete from 2005. For the experienced engineers, with the shift of the structural design principles, the performance-based design of steel structures with the increasing applications requires utilizing the experimental data to confirm performances of a new structure on the deformation, the energy absorption, the seismic capacity and others. Users can benefit from the useful information of the database for learning, referring, and utilizing the test data, and contribute themselves to update the database by contacting the database administrator if they have ideas to make this system used widely or extend the database system.

Classification of Experimental Types

At the present central database server, two types of structural steel experiments have been installed, which are the seismic experiment including the cyclic loading test (JRA 2000, Kawashima 2001) and the pseudo-dynamic test (JRA 2000, Kumar et al. 1997) and the ultimate strength experiment (Itoh 1984). The seismic experiments mainly contain the cyclic loading experiment and the pseudo-dynamic experiment of the steel pier for the single-column type with the consideration of the effect of local buckling. The ultimate strength experiments originally installed in NDSS at Nagoya University was shifted to the current database server and is under the support of the Internet (Itoh 1984).

The results of 431 individual seismic tests, including 286 and 145 for the cyclic loading tests and the pseudo-dynamic tests respectively, are categorized into 5 experimental types according to their specimen types of columns as shown in Table 1, which are the piers of the un-stiffened column, the stiffened column type, the un-stiffened column type with concrete, the stiffened column type with concrete, and the pipe type. Some of seismic tests include the displacement history in the dynamic loading, and the number on the parentheses represents these types of tests in Table 1. The numbers of the ultimate strength tests imported from NDSS are shown in Table 2. The total 5653 individual tests are categorized into 5 types according to their specimen types that are the steel column, the steel beam, the steel plate, the plate girder and the steel material properties.

Table 1 Specimens of Cyclic Loading and Pseudo-dynamic Test

Experimental type	Un-stiffened pier	Stiffened pier	Unstiffened pier with concrete	Stiffened pier with concrete	Pipe-section pier	Total
Cyclic loading	54 (21)	142 (37)	41 (5)	36 (2)	13 (7)	286 (72)
Pseudo-dynamic	28 (3)	25 (2)	22 (3)	70 (1)	0 (0)	145 (9)

Table 2 Specimen List of Ultimate Strength Tests of Structural Steel Components

Shapes	Steel column	Steel beam	Steel plate	Plate girder	Steel material properties	Total
Numbers	1665	554	793	333	2308	5653

Identification of Experimental Data

In the actual database, the multimedia information types of both the seismic experiment and the ultimate strength experiment consist of four types of data: (1) Numerical data: Numerical data are classified to be the model shape and cross section data; the model materials; the load data; and the analysis data; (2) Text data: The database includes the textual information of the technical papers and other materials related to the tests and analyses such as the test objectives and methods; (3) Images: Test images include the failure images, test diagrams, arrangement of test equipment, and diagrams to determine the position of the measurement point such as strain gages and displacement transducers; and (4) Videos: Video data are the edited scenes of the test that can help the users to grasp the dynamic tests such as the behavior of the specimen collapsing in the pseudo-dynamic experiment.

All these data are useful for users to know the details about the structural tests. At present, the database developed in this research consists of only three types of data including the numerical data, the textual data, and the image data, and the videos recording the test preparation and procedure are still managed in the form of tapes. All above data are helpful to understand the entire test from various sides.

DEVELOPMENT OF A DISTRIBUTED COLLABORATION DATABASE SYSTEM

Needs of A Distributed Collaboration Database System

The distributed collaboration database system for realizing the share of the experiment data has been developed, in which researchers release their own experimental data on their own servers. Under the distributed collaboration system, users can refer all of data through accessing to the central metadata serve including the host and distributed databases. Such a distributed collaboration database system has the following advantages: (1) the burden of network and server load is less than those of ordinary databases; (2) the trouble occurred at the server side is avoidable to some extent; (3) the whereabouts of responsibility are clear because of the self-responsibility of researchers, and the released range of experiment data can be left to discretion of each experiment researcher; and (4) when data have changed, researchers can easily update data at their own servers.

The role of the system administrator in Nagoya University is not collecting and releasing data, but managing the metadata such as the properties and the data locations from one experiment. This method enables users to deal with the distributed data systematically. The central metadata server and Web interface support researchers to develop their own experiment database. Metadata applied to the structural steel experiment is created by following a standard of the Dublin Core as described in detail in 5.2. XML (eXtensible Markup Language) is used to represent the metadata.

System Functions

The functions prepared in the system are: (1) Search of experiment metadata, (2) Registration and revision of experiment metadata, (3) Perusal and graphics of experiment data, (4) Download of experiment data, and (5) Registration and attestation of users. The first two functions will be described as follows: (1) Two kinds of searching methods of experiment data are developed. One is the simple search that can be quickly performed from a top page, and the other is the detailed search. In the simple search, the required information can be searched with a single keyword. In the detailed search, it can be searched with plural keywords and more keywords are available. After the search, perusing and downloading the experiment results are possible with the tracing links. (2) Researchers firstly have to register their personal information to install their own experiment metadata to the system. This is for preventing a general user from registering unrelated information. The registered researchers can get the password for login. Logging in to the system attains the registration of experiment metadata. In the system, the numerical data of experiments can be registered from Web. The numerical data registered here is used as one key in the case of searching of data. The researchers can revise the registered contents also.

Experiment Information Metadata

The Dublin Core (the Dublin Core Metadata Element Set) is advocated by standardization activities of the metadata on WWW, and has been used originally in the field of natural history by the Dublin Core Metadata Initiative (2005). The fundamental purpose of the Dublin Core is to make easy to retrieve the information resources on the Web. In the Dublin Core, 15 items of metadata are defined for the improvement of the retrieval efficiency on the Web.

In the system developed in this research, the metadata server that manages the metadata of the experiment data plays a main role. Most of data items are following the standard of the Dublin Core. Some items are modified and several sub-elements are added for dealing with experiment information, and a new item to represent the specimen is added. The list and concise explanations of these data items are: (1) Language: The language that is described the outline of information resources; (2) Title: The title of experiment; (3) Creator: The person or organization who has responsibility about the contents of information resources. In this research, an attribute, name and E-mail address are added as the sub-elements of this item; (4) Contributor: The person or organization in connection with [although it was not an author] the contents of a document. In this research, 3 sub-elements are added; (5) Publisher: The person who made information resources the present form. In this research, 3 sub-elements are added; (6) Date: The date that can be used in the present form. For example, the year of experiment data released; (7) Subject: The topic stated to information resources such as procedures of experiment; (8) Specimen: Information about specimen. This item has 3 sub-elements: Name (Name or amount of specimen), Type (The model of specimen), and Description (Supplementary explanation); (9) Relation: Correlation with other information resources; (10) Description: Description about the contents of an outline, image data, etc.; (11) Right: The links to the description about rights, such as copyright description or the description about use conditions; (12) Data: Information about experiment results. This item has 3 sub-elements: Type (Contents of data), Format (Format of file), URL (URL of stored data). Data item is not original element following the Dublin Core, added newly in the research. The system of the metadata server stores numerical data in Data item, such as height of column, width of flange plates, yield stress, and yield moment; (13) Identifier: The number or name for discriminating information resources uniquely; (14) Type: information resources like WebPages, dictionaries, and so on. This item is “Experiment data” in this research; (15) Source: The number or character string which shows the source of information resources; and (16) Coverage: The characteristic of the information resources about a geographical place or the time contents. This item is empty, because suitable information doesn’t exist in experiment data information. The Dublin Core allows empty in some items.

Database Development Environment

As this database system treats a combination of numerical data, text data, image data and graphics extensively, the hardware of the database should have a fast processing speed, and a large memory space. For these reasons, the development platform used for the preparation of this database is the Sun workstation. The server operation system and web server are the Solaris 2.6 and Sun web server, respectively. In the future, the database for steel structural experiments may be distributed in several computer platforms by taking the advantages of the Internet while more civil engineers are capable of handling the network server.

Because the database is developed on WWW, users need the browser which has Virtual Machine (VM) with the Java version over 1.1 (Netscape Communicator 4.5 or Internet Explorer 4.0 is recommended) in order to access the database. The main purpose of this database system is to make it possible to access the structural steel experimental data and numerical analysis through the Internet. Some functions and contents of the database on both the seismic test results and the ultimate strength test results will be introduced in the following chapter.

Interface Development

In 1989, the Conceil Europeenee Pour la Recherche Nucleaire (CERN) in Europe published the first World-Wide Web system which made multimedia data including images, sounds, and literature document as well easily treatable on the Internet. However, in the WWW system based on the HyperText Markup Language the server can deliver only created documents consisting of the text, images, and so on. When the interactive operations such as searching data are carried on, special programs are needed. One of such special programs is Common Gateway Interface (CGI) that is usually developed with C or Perl language. In this interface program system, when the request from the client is made, the server can carry out the required operation and send the information interactively. Another program is Java that is an object-oriented program language available for the Internet use. Original programs called "applet" can be made using Java, which are sent to the client. Those original programs can also be exerted at the client and shown on the browser as if they are a part of the document. The architecture of applet is shown in Figure 1. Java enables to deal with more issues than CGI does. In addition, since applet is exerted at the client's CPU, the information processing at the network level, which is the so-called distributed computing, can be performed by Java easily (Lemay 1995). However, it is difficult to achieve using CGI. As far as the development of the user-interface and the distribution computing system of this database concerns, using Java is considered to be a suitable adoption. Therefore Java is used in this research for developing the database. This database is not developed only to display the experimental numerical data, but also to make the experiment procedure to be explained comprehensively through various types of information including the image data, the experimental process, and the purpose of each experiment by taking the advantage of WWW. In this way, the integrated information related to each experiment can be provided. In addition, the database has been developed aiming flexibility and generalizing in order to be able to respond the updated progress in the distributed collaborative environment.

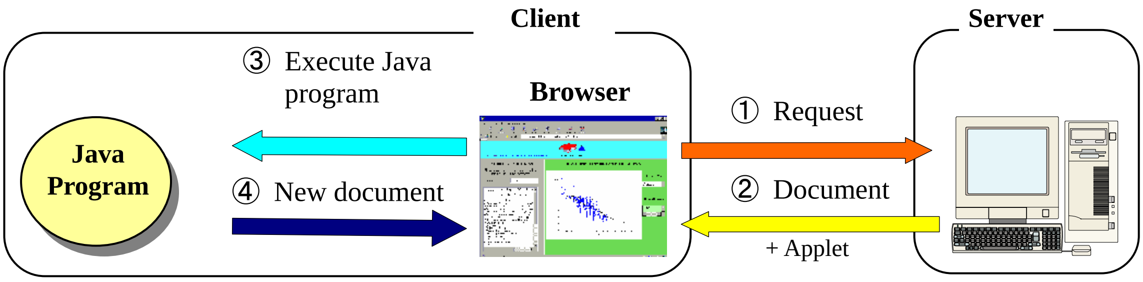

Figure 1 Java-Based Client Server Interactions

APPLICATIONS OF THE DATABASE FOR EXPERIMENTAL OUTCOME ANALYSIS

Seismic Test Results of Steel Piers

Figure 2 shows an example to retrieve the results of cyclic loading tests. Once the shape and name of specimen are chosen, the details about the specimen such as dimension can be retrieved. In addition, the available image and graph of the history of the displacement can be visualized in another window such as the Load-Displacement indexed as U5-2C as shown in this figure. A similar approach can be applied to retrieve the results of the pseudo-dynamic tests. Given the parameters for search, the graphics of the input earthquake wave, the time-displacement relationship, and the load-displacement relationship can be generated from the system.

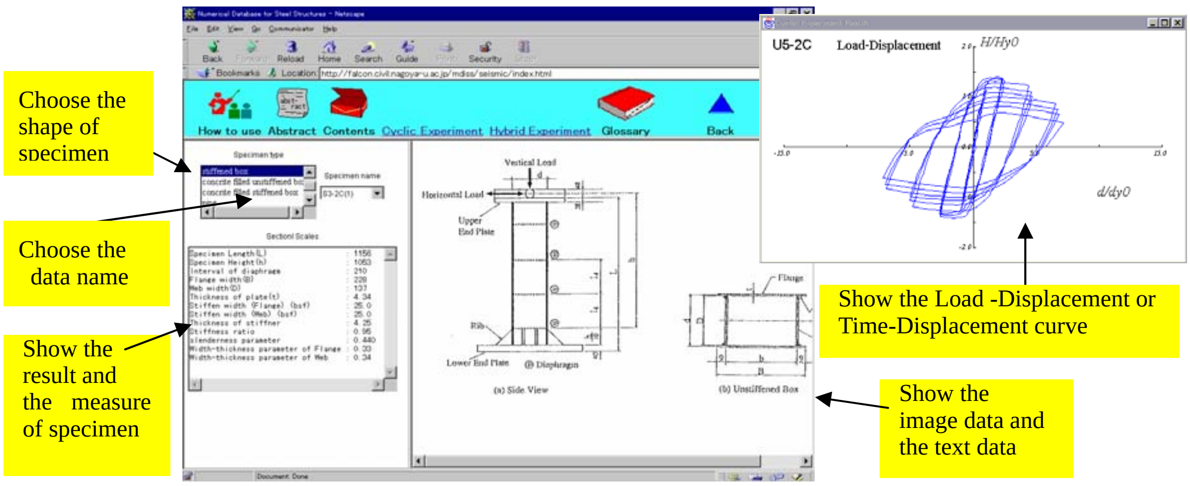

Figure 2 Retrieval Result of Cyclic Loading Test

Ultimate Strength Test Results of Structural Steel Members

Figure 3 shows an example of the window of the column data in the database using the Netscape browser. The horizontal axis of the right hand side figure means the non-dimension buckling parameter of the slenderness parameter $\bar{\lambda}$, and the vertical axis represents the non-dimension value *Fu/Fy*, where, *Fu* is the maximum load, and *Fy* is the measured yield load. Furthermore, the Euler's buckling curve or some other kinds of design curves are also plotted on the graph for the purpose of comparison. The parameter option form in the right side of the window enables to choose the shape of specimens and the non-dimensioned value of test results. In addition, the database has a function to represent the specimen number whose result point is clicked by mouse on the graph at the bottom right. When the specimen number is inputted in the field of the left side of this graph, the specimen data are represented in detail under the input field. The database enables to compare the test results and some design curves.

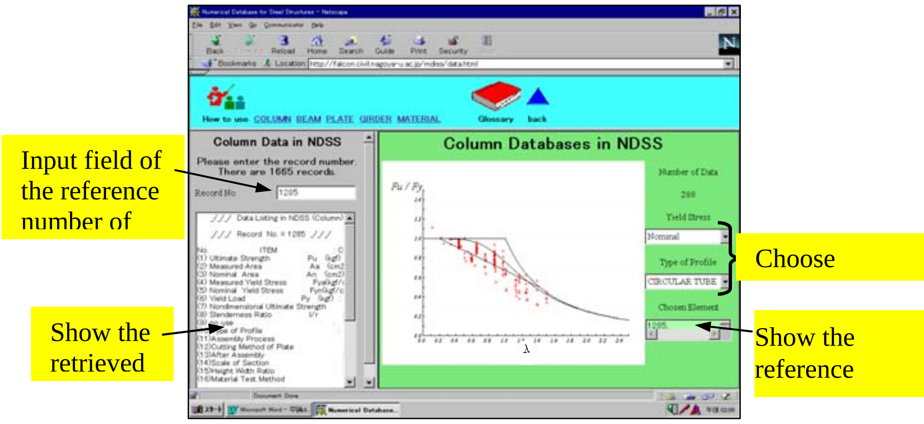

Figure 3 Ultimate Strength Test Results of Steel Columns

DATABASE APPLICATIONS IN BENCHMARK TEST OF STRUCTURAL NUMERICAL ANALYSIS

Implementation Processes of Seismic Analysis Based on the Distributed Collaborative Database

By using the distributed collaboration database system, the analysis data are shared efficiently. In the system, the original analysis data are released and managed by researchers and engineers who conducted the numerical analyses, and the system administrator of the central database server gives only the suggestion how to install the original data onto data servers. The main role of the system administrator is management of the metadata having the properties of original data. Under the distributed collaboration system, users can refer all of data through accessing to the central metadata server. The main advantages are: (1) The burden of network and server load is less than that of ordinary databases; (2) The trouble occurred at the server side is avoidable to some extent; (3) The whereabouts of responsibility are clear because the released range of analysis data is left to discretion of each data creator; and (4) Each data creator can easily update the data at his/her own server.

In this study, the central database server storing metadata of analysis results has been established in Nagoya University. XML (eXtensible Markup Language) was used to describe the metadata. Database software to store metadata of analysis results was eXcelon (the product made from eXcelon) in which XML was stored directly. Java was also used for the process between a database server and users. Figure 4 describes the processes in a database server when the users search the metadata. The database server receives strings following SQL. Then a database server searches the metadata or adds new metadata on analysis results following the strings. Java translates searching keywords inputted by users into SQL strings that database can deal with.

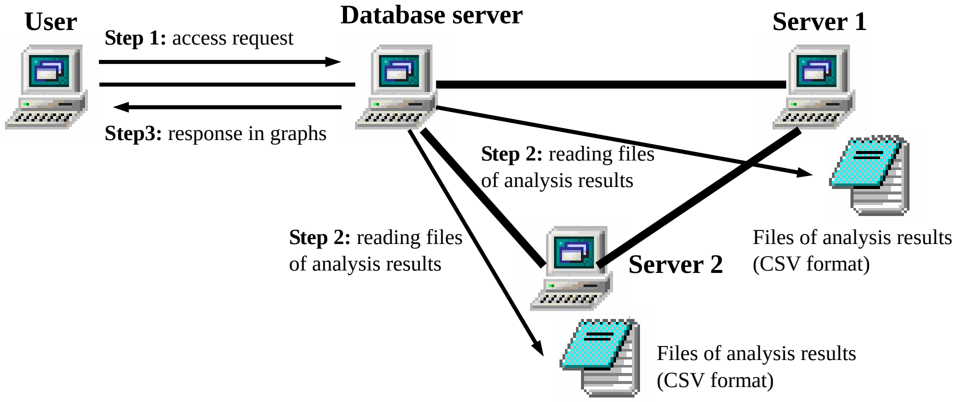

Figure 4 Implementation Processes of Seismic Numerical Analysis

The files of numerical analysis results such as restoring force history curve are prepared as CSV file format in remote servers. Moreover, the server has the function that draws graphs from a file of numerical values of analysis results. As a summary of the processes, in Step 1, the database server receives a request of viewing graphs from users; in Step 2, the database server read corresponding CSV file (file of numerical results of analysis) requested by users; in Step 3, the database server generates graphs from the numerical results; and in Step 4, the database server returns graphs in JPEG format to users Using Java, which allows the system developers to avoid preparing the picture file of graph in advance and to add data with simple procedures.

Benchmark Test of Structural Numerical Analysis

The database system developed in this study also provides the retrieval and modification functions of the benchmark data. These functions are allowable for the registered users in consideration of the system security and data accuracy. In retrieval of benchmark data, retrievals by keywords on an analysis title, an analysis organization, a creator of the data, an analysis model, and an analysis year are available. The typical retrieval keywords are embedded to each item in advanced so that even users with little experience can operate this system easily. Creators of analysis data can install, correct and delete the data that contain 15 Dublin Core elements, the URL of data file of numerical results and a file for explaining the analysis models (for example, graphics, photos and text files). In the cases of installation, corrections and deletions of metadata of the benchmark data on Internet, the registration as a data creator of the database is required. This is for preventing registering unrelated data and an alteration of benchmark data being performed by unjust use. The perusal page of tree view was developed about the data prepared. On this system, numerical values, graphs, and metadata can be compared simultaneously. Then, a display was divided into four fields as shown in Figure 5, including (1) menu field, (2) analysis result display field, (3) metadata display field and (4) graph display field. Users can download numerical results files and graph files in JPEG format. It should be noticed that the installation of some experimental data into the server was purposely in an external network to test the performance of the distributed database and metadata.

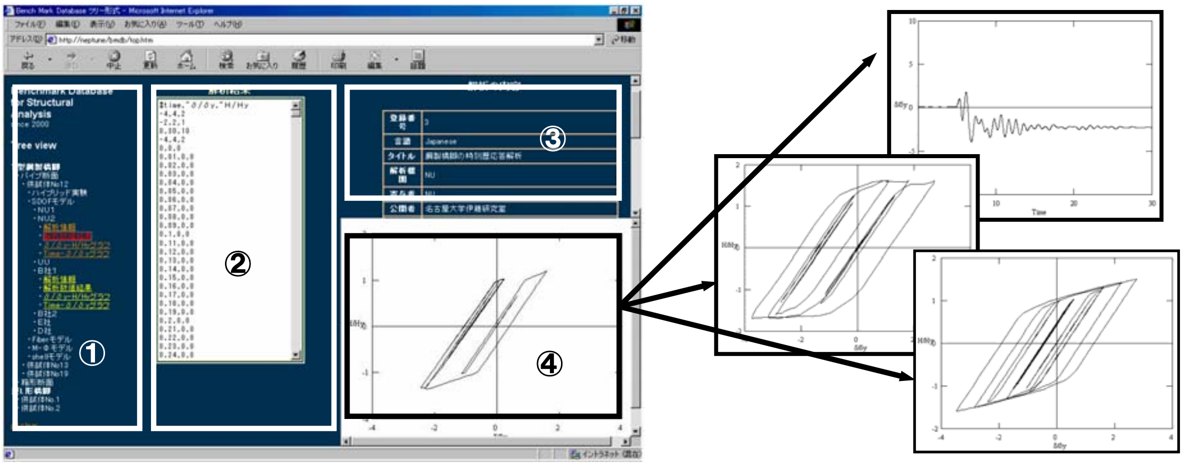

Figure 5 Benchmark Test of Structural Numerical Analysis

Performance-based Design and Analysis of Bridge Guard Fences

In addition to steel bridge structures, performance-based design has been prevalent for bridge guard fences, in which new technologies can be easily configured, compared with regulation-based design. For example, a new code under the performance-based design concept was effective in April 1999 in Japan. The first author of this paper has been leading a research project to develop another distributed collaborative database for experimental and analytical results of bridge guard fences subjected vehicle collisions. Figure 6 shows an example in the current database. Parts (a) and (b) are the FEM models of bridge guard fences and a truck respectively, which were originally developed in Nagoya University. Parts (c), (d) and (e) compare the visual performances of both the truck and guard fences after 0.2 second of collision, which are obtained from an experiment, a numerical analysis using LS-DYNA (for short, Analysis 1) and another numerical analysis using PAM-CRASH (for short, Analysis 2) respectively. Studies have been carried out to investigate the quantitative performances of both vehicles and guard fences including displacement responses, forces and energy absorption and shits during and after the collision. In Part (f) of Figure 6, the displacement responses of a guard fence column within 0.7 seconds after collision are represented for these three cases. The benchmark data obtained from both experiments and analyses are being maintained in a metadata server and will be made possible for retrieval and modification by registered users through a distributed collaborative database system.

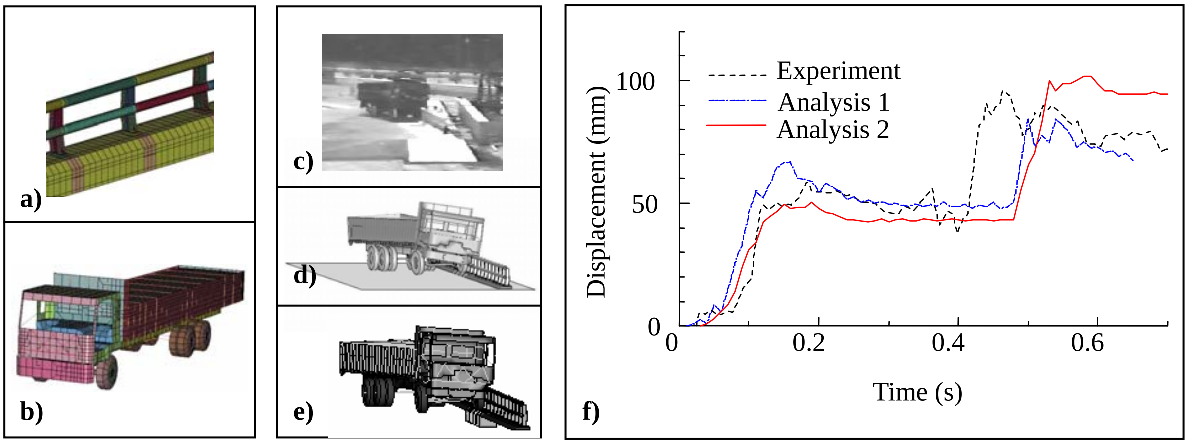

Figure 6 An Example of Performance Analysis of Bridge Guard Fences Subjected to Vehicle Collision

CONCLUSIONS

(1) Seismic experimental data have been gathered and arranged, and a distributed collaborative database system for structural steel experiments was developed on WWW. An existing test database of ultimate strength of structural steel members was also shifted to this system. It was proved that Java is an effective programming language to develop such an interactive system for retrieving test data interactively and making the graphical user interface.

(2) The system was developed to be able to generate some valuable coefficient and formulation from the statistical viewpoint. The system was developed to be able to supply more information to the users with the increase of available data in distributed servers.

(3) A distributed collaboration system releasing the structural steel experimental data has been developed. As the standard of metadata, the Dublin Core is applied to deal with the experiment metadata. XML is used for description of metadata of the structural experiment results. The applications of the developed database system for both experimental results retrieval and seismic numerical analysis were validated in examples using the registered experiment metadata. The development of a database system on performance-based design and analysis for bridge guard fences is also introduced briefly in this paper.

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