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Development and applications of an experimental database for structural engineering education

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ABSTRACT: A great number of research organisations in Japan have been conducting structural steel experiments for many years, particularly seismic tests of steel structures like cyclic-loading and pseudo-dynamic tests, in order to determine their seismic performances. However, the original test data gained by most research organisations are not well stored in an appropriate manner for distribution and possible usage by others. With the rapid development of information networks, structural engineers and researchers are able to exchange various types of test data through the Internet. In this paper, the authors present the development of a distributed collaborative database system for structural steel experiments. The database is made available on the Internet, and the use of Java language enables efficient interactive retrieval. The potential applications of the developed database system for structural engineering education are validated for the retrieval of experimental data and seismic numerical analysis.

INTRODUCTION

Since the Great Hanshin earthquake in 1995, Japanese engineers and researchers in civil engineering have been subjected to increasing social pressure and professional responsibility to improve the behaviours of civil infrastructure against natural disasters [1][2]. Seismic tests, such as cyclic-loading and pseudo-dynamic tests, have been conducted in many research organisations in order to determine the seismic performances of steel structures. However, only a part of the data from these tests have been published for the public as reports or papers, and most of the details, such as the dimensions and failure types of specimens, are stored locally in an inappropriate manner for distribution and possible usage by others.

In order to preserve and share experimental data, a Numerical Database of Steel Structures (NDSS) has been developed and upgraded at Nagoya University since the 1980s [3-5]. This database has been referred to as the basic data for the revision of various specifications on steel structures over the world. However, taking into account the issue of access from outside the University, this database is not efficient from the viewpoint of both hardware and software, although efforts have been made to utilise information technology and a knowledge management approach to strengthen the original database.

Due to the establishment of the World Wide Web (WWW) and the related development of browsers such as *Mosaic*, *Netscape*, and *Internet Explorer*, the Internet has become an indispensable tool like the computer itself, and has provided fresh opportunities for researchers and engineers in civil engineering to utilise the structural steel experimental data more efficiently. Previous research also demonstrated the potential for Web-based enhancements in the design and construction of a complicated project [6]. For example, a Web-based information system has been developed for promoting management methodologies for demolition projects [7]. The Internet has also been used to perform real and virtual experiments [8][9]. East et al. carried out an in-depth analysis of the impact of Web collaboration [10].

In this research, a distributed collaborative database system was developed to collect and combine seismic and ultimate-strength test results in the form of numerical data, text data, images and videos. The database system is developed on a metadata server and the collaborative databases are administered in various servers through the Internet. As a result, users, such as engineers, researchers, academics and students, are able to retrieve the test databases stored in remote servers of various organisations and to perform seismic numerical analyses by accessing the central metadata server.

DEVELOPMENT OF A DISTRIBUTED COLLABORATION DATABASE SYSTEM

Needs of a Distributed Collaborative Database System

The Internet is literally growing because of its interaction with human behaviour and habits [11]. 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, either an expert in civil engineering or an undergraduate student can access the proposed database through the WWW from various types of computer platforms like Macintosh, Windows and Solaris for the purposes of education, research or communication. The proposed database system contains the client and server sides, as well as the WWW. With the user interface has been designed using the HyperText Markup Language (HTML) program and the Java program, the database storing the structural steel experimental data can be enriched with, and accessed in, the form of photos and digitised information, in addition to numerical and textual data.

The potential to develop a Web-based collaborative database for structural steel experiments is derived from the capacities of the Internet, including communication technology, user interface, multimedia data, search engines, and vast and constantly updated information. 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. The WWW browser involves easy operations so that few users need 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. The availability of automated text search engines in Web browsers is one important technical development, by which the structural engineers can discover the locations of the attainable databases quickly, efficiently and accurately. Vast amounts of information on the Internet can be updated and accessed constantly through different computer platforms. Engineers or researchers who have carried out experiments can present their ideas, concepts and the strategy of a specific experiment over the Internet, and can make them available to be downloaded easily and for free.

The distributed collaboration database system for realising the share of the experiment data has been developed in which researchers release their own experimental data on their own servers. Under the distributed collaborative system, users can refer to all data through accessing to the central metadata server, including the host and distributed databases. Such a distributed collaborative database system has the following advantages:

- The burden of network and server load is less than those of ordinary databases;
- The trouble occurring at the server side is avoidable to some extent;
- The whereabouts of responsibility are clear because of the self-responsibility of researchers, and the released range of experiment data can be left to the discretion of each researcher's research work;
- When data have changed, researchers can easily update data on their own servers.

The role of the system administrator is not to collect and release data, but rather to manage 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, described in more detail below. The eXtensible Markup Language (XML) is used to represent the metadata.

System Function Analysis

The functions prepared in the system include a search of experiment metadata, registration and revision of experiment metadata, perusal and graphics of experiment data, download of experiment data, and registration and attestation of users. The first two functions are described here. Two kinds of searching methods of experiment data have been developed, which are the simple search quickly performed from a top page, and 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.

Furthermore, researchers have to register their personal information to install their own experiment metadata to the system. This is to prevent a general user from registering unrelated information. Registered researchers can obtain a login password. Logging in to the system attains the registration of experiment metadata. In the system, the numerical data of experiments can be registered from the Web. The numerical data registered here is used as one key in the case of searching for data. Researchers can also revise their registered contents.

Different from the WWW system based on HTML, in which the server can deliver only created documents, interactive operations, such as searching data request special programs like the Common Gateway Interface (CGI), are 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, which is an object-oriented program language available for Internet usage. Original programs, called *applets*, can be made using Java, which are then sent to the client. Those original programs can also be executed at the client and shown on the browser as if they are a part of the document. The architecture of an applet is shown in Figure 1. Java enables the user to deal with more issues than CGI does. In addition, since an applet is executed at the client's CPU, information processing at the network level, which is the so-called distributed computing, can be performed easily by Java. 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 was used in this research to develop the database.

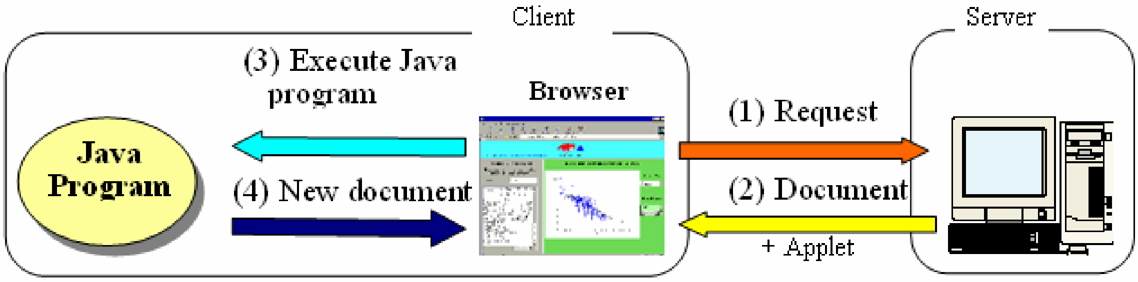

Figure 1: Java-Based client server interactions.

This database has not been developed only to display the experimental numerical data, but also to allow 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 advantage of the WWW. In this way, the integrated information related to each experiment can be provided and student users can learn by themselves through navigating the online experiment data. In addition, the database has been developed aiming at flexibility and generalising so that it can update the progress in the distributed collaborative environment.

Experiment Information Metadata

The Dublin Core (the Dublin Core Metadata Element Set) is advocated by standardisation activities of the metadata on the WWW, and has been used originally in the field of natural history by the Dublin Core Metadata Initiative [12]. The fundamental purpose of the Dublin Core is to make it easy to retrieve 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, most data items follow 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 has been added. These data items are as follows:

- The language that is used to describe the outline of information resources;
- The title of experiment;
- The person/organisation responsible for the contents of information resources (an attribute, name and e-mail address are added as the sub-elements of this item);
- The person or organisation in connection with the contents of a document (three sub-elements were added);
- The person who made the information resources in the present form (three sub-elements were added);
- The date that can be used in the present form (for example, the year of experiment data released);
- The topic stated to information resources, such as the procedures of experiment;
- Information about a specimen, which includes three sub-elements, namely Name (name or amount of specimen), Type (the model of specimen) and Description (supplementary explanation);
- Correlation with other information resources;
- Description about the contents of an outline, image data, etc;
- The links to the description about rights, such as copyright description or the description about usage conditions;
- Information about experiment results, which has three sub-elements, namely Type (contents of data), Format (format of file) and URL (URL of stored data);
- The number or name for discriminating information resources uniquely;
- Information resources like Web pages, dictionaries, and so on, which is *experiment data* in this research;
- The number or character string which shows the source of information resources;
- The characteristic of the information resources about a geographical place or the date, which is empty as suitable information does not exist in experiment data information and the Dublin Core allows some items to be empty.

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 Solaris 2.6 and the Sun Web server, respectively. In the future, the database for structural steel experiments may be distributed through 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.

DATABASE-ASSISTED ANALYSIS ON EXPERIMENTAL RESULTS

Identification and Classification 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: which are numerical data, text data, images and videos. Numerical data are classified to be the model shape and cross section data; the model materials; the load data; and the analysis 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. 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. Video data are the edited scenes of the test that can help the users to grasp the dynamic tests such as the behaviour 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 perspectives.

On the present central database server, two types of structural steel experiments have been installed, which are the seismic and ultimate strength experiments. The seismic experiments mainly contain the cyclic loading experiments [1][13] and the pseudo-dynamic experiments [13][14] for the single-column steel piers 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 [3].

The results of 431 individual seismic tests, including 286 and 145 for the cyclic loading tests and the pseudo-dynamic tests respectively, are categorised into five experimental types according to their specimen types of columns, as shown in Table 1, which are unstiffened piers, stiffened piers, unstiffened piers with concrete, stiffened piers with concrete, and pipe-section piers. Some of seismic tests include the displacement history in the dynamic loading, with the number in the parentheses representing these types of tests in Table 2.

Table 1: Specimen list of ultimate strength tests of structural steel components.

Shapes	Numbers
Steel column	1,665
Steel beam	554
Steel plate	793
Plate girder	333
Steel material properties	2,308
Total	5,653

Table 2: Specimens of cyclic loading and pseudo-dynamic test.

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

Furthermore, the numbers of the ultimate strength tests imported from the NDSS are shown in Table 1. All 5,653 individual tests have been categorised into five types according to their specimen types, ie steel column, steel beam, steel plate, plate girder and steel material properties.

Seismic Test Results of Steel Piers

Figure 2 shows an example on how retrieve the results of cyclic loading tests. Once the shape and name of specimen have been chosen, the details about the specimen, such as its dimension, can be retrieved. In addition, the available image and graph of the history of the displacement can be visualised in another window, such as the load-displacement indexed as U5-2C shown in Figure 2.

A similar approach can be applied to retrieve the results of the pseudo-dynamic tests. Given the search parameters, the graphics of the input earthquake wave, the time-displacement relationship and the load-displacement relationship can be generated from the system. With the increase of the test data gathered and managed in the form of databases, some statistical approaches have been applied for recognising the characteristics of materials and structures, such as the ultimate strength and ductility analyses [13].

This database includes a function to draw the graph of the relationship along major parameters like the slenderness parameter $\bar{\lambda}$, the width-thickness parameter of flange R_f and the maximum displacement H_{max}. In addition, a function to estimate an approximated equation by means of a non-linear minimum square method has been added. The more data that are appended in the future, the better the information will be that is supplied to users.

Figures 3a and 3b show the cyclic loading test results of unstiffened and stiffened specimens, respectively. The vertical axis in the figure means H_{max}/H_y while the horizontal axis means the product of R_f and $\bar{\lambda}$. This product value in the horizontal axis has been found to have a good correlation with the value of *Hmax/Hy* [13]. The solid curve in the figure represents the mean curve, and the dashed curve represents the lower limit curve, which is calculated by the mean value minus the standard deviation.

Figure 4 shows the distributions of actual steel piers retrieved from the database. The data include the width-thickness parameter of flange R_f, the slenderness parameter $\bar{\lambda}$, and the plate thickness of flange *t*.

On the width-thickness parameter R_f, the mean value of the distribution is 0.52. The mean value of the slenderness parameter $\bar{\lambda}$ from the database is 0.41. With respect to the distribution of flange thickness *t*, it should be noted that the tests of about 4 mm flange model specimen have been performed well.

Ultimate Strength Test Results of Structural Steel Members

Figure 5 shows an example of the window of the column data in the database using the *Netscape* browser. The horizontal axis

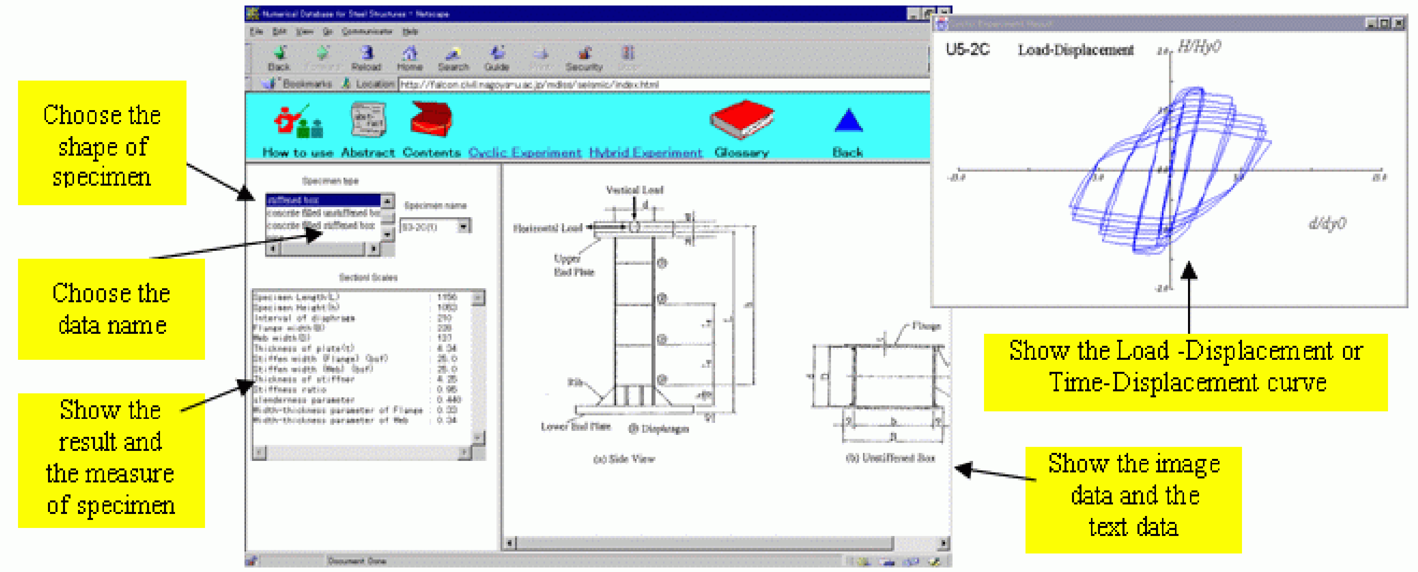

Figure 2: Retrieval result of cyclic loading test.

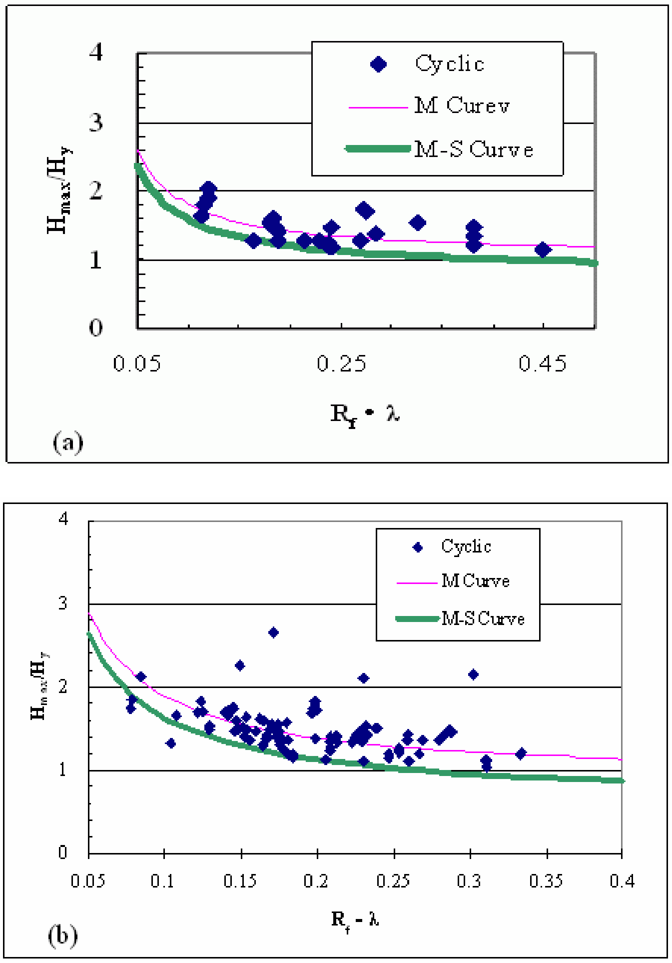

Figure 3: Cyclic loading test results.

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 other design curves are also plotted on the graph for the purpose of comparison. The parameter option form on the right side of the window enables the selection of 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 a comparison of the test results and some design curves to be made.

DATABASE-ASSISTED BENCHMARK TEST OF STRUCTURAL NUMERICAL ANALYSIS

Implementation Processes of Seismic Analysis

By utilising 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 as to how to install the original data onto data servers.

The main role of the system administrator is the management of the metadata having the properties of original data. Under the distributed collaboration system, users can refer to all data by accessing the central metadata server. In this study, the central database server storing the metadata of analysis results has been established at Nagoya University. XML was used to describe the metadata. Database software to store metadata of analysis results was eXcelon (a product made by eXcelon) in which XML was stored directly. Java was also used for the process between a database server and users.

Figure 6 describes the processes in a database server when the users search the metadata. The database server receives strings following SQL. A database server then searches the metadata or adds new metadata on analysis results following the strings. Java translates searching keywords inputted by users into SQL strings that the database can deal with.

The files of numerical analysis results, such as restoring the force history curve, are prepared in CSV file format at remote

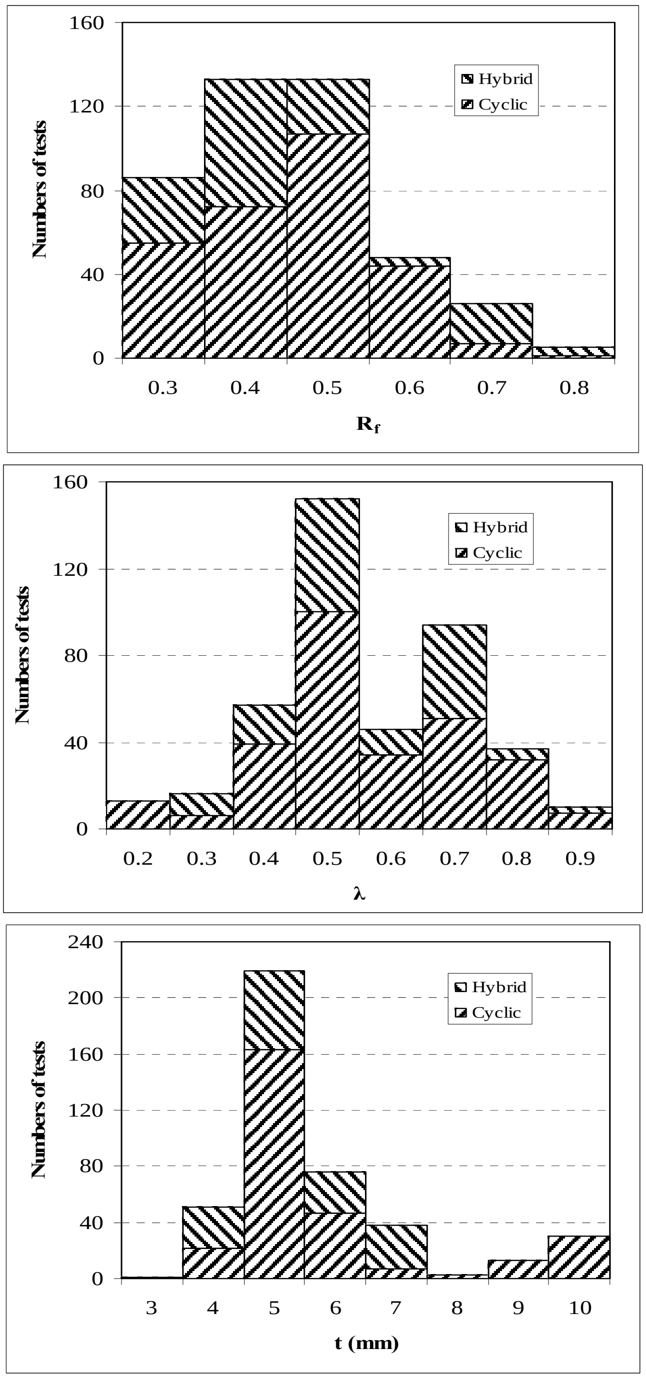

Figure 4: Distributions of seismic specimen profiles.

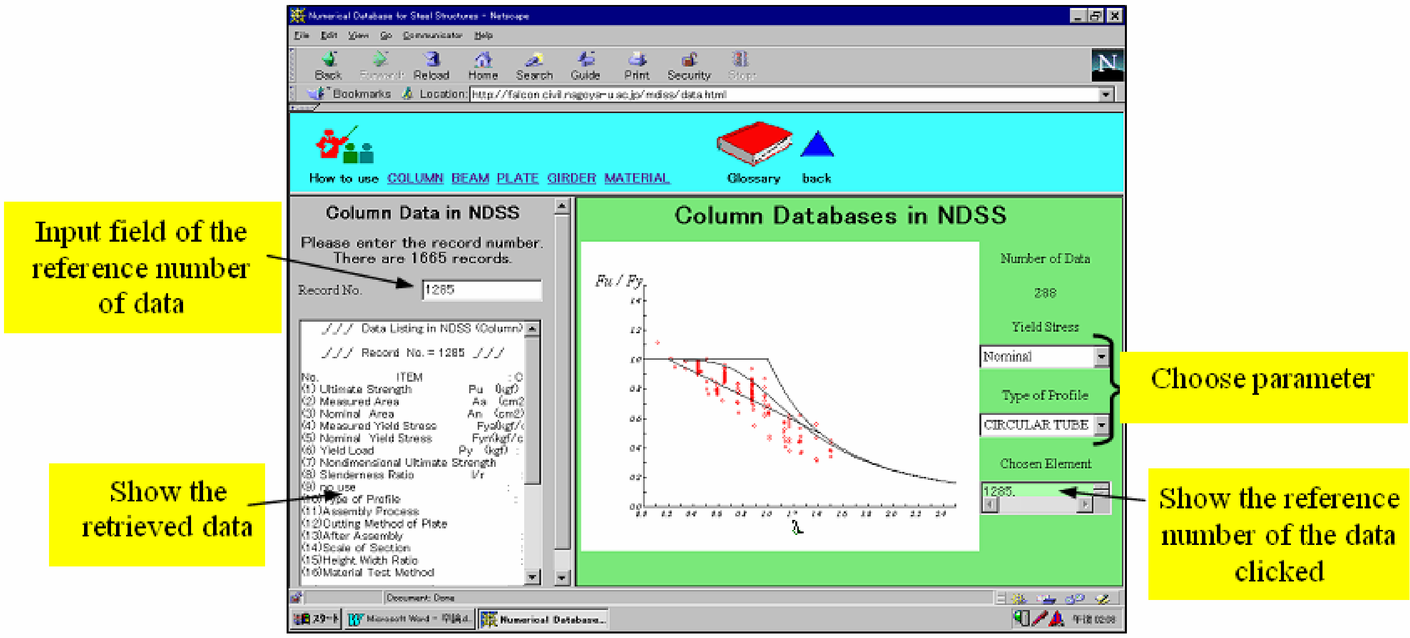

Figure 5: Ultimate strength test results of steel columns.

servers. Moreover, the server has the function that draws graphs from a file of numerical values of analysis results. A summary of the process is as follows:

- Step 1: the database server receives a request of viewing graphs from users;
- Step 2: the database server reads the corresponding CSV file (file of numerical results of analysis) requested by users;
- Step 3: the database server generates graphs from the numerical results;
- 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 a 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 registered users in consideration of system security and data accuracy. The retrieval of benchmark data is achieved by keywords of an analysis title, analysis organisation, data creator, analysis model or analysis year. Typical retrieval keywords are embedded into each item in advance so that even users with little experience can easily operate this system. Creators of analysis data can install, correct and delete the data that contain the 15 Dublin Core elements, the URL of the data file of numerical results and a file for explaining the analysis models (such as graphics, photos and text files). In the cases of installation, corrections and deletions of metadata of the benchmark data on Internet, registration as a data creator of the database is required. This is to prevent registering unrelated data and an unjustified alteration of benchmark data being performed. The perusal page of tree view was developed about the data prepared.

In this system, numerical values, graphs and metadata can be compared simultaneously. A display can then be divided into four fields, as shown in Figure 7, including menu field, analysis result display field, metadata display field and graph display field. Users can download numerical results files and graph files in JPEG format. It should be noted that the installation of some experimental data into the server was purposely taken from an external network so as to test the performance of the distributed database and metadata.

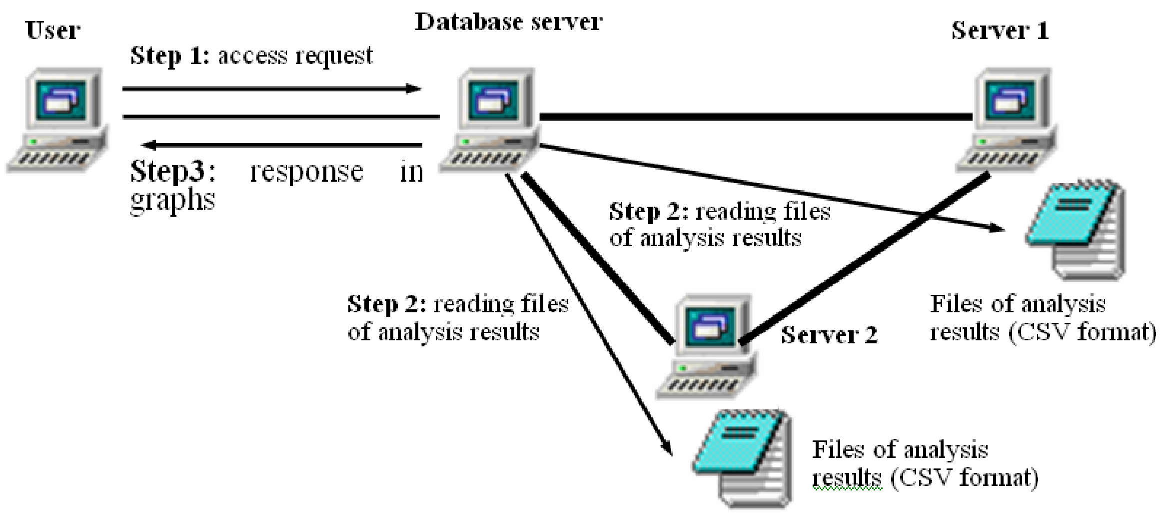

Figure 6: Implementation processes of seismic numerical analysis.

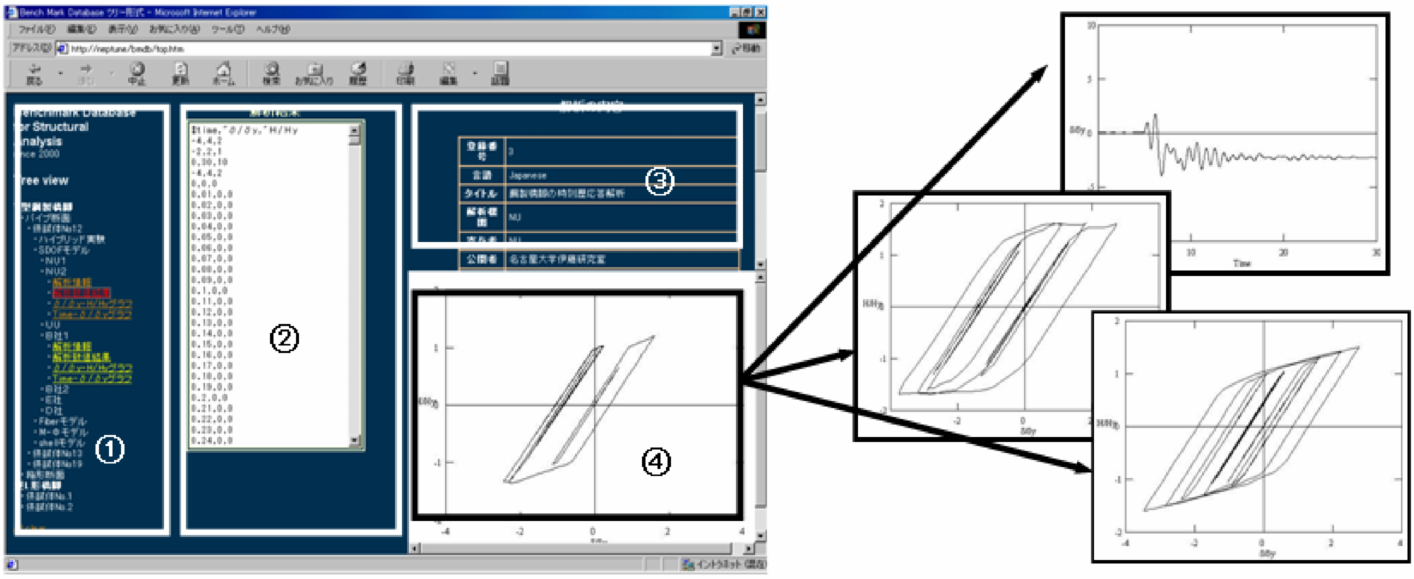

Figure 7: Benchmark test of structural numerical analysis.

CONCLUSIONS

The research presented in this paper describes a distributed collaborative database system that was developed for experimental data sharing for steel structures and numerical analyses of their seismic performances. The potential applications of this database system are also demonstrated for structural engineering education in terms of the retrial of experimental data and seismic numerical analysis. Based on this research, the following conclusions can be stated.

Seismic experimental data have been gathered and arranged, and a distributed collaborative database system for structural steel experiments was developed on the 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.

The system was developed for users such as researchers and students in order to be able to generate valuable coefficients and formulations from a statistical viewpoint, and to supply more information for its further development. The developed database system provides an Internet-based warehouse on structural experimental data for both research and education.

A distributed collaboration system releasing the structural steel experimental data has been developed. As the standard of metadata, the Dublin Core has been applied to deal with the experiment metadata. XML has been used for the description of the metadata of the structural experiment results. The applications of the developed database system were validated for both experimental results retrieval and seismic numerical analysis using examples.

REFERENCES

1. Kawashima, K., Cyclic Loading Test Data of Reinforced Concrete Bridge Piers. Tokyo: Earthquake Engineering Committee, Japan Society of Civil Engineers (2001).
2. Japan Society of Civil Engineers (JSCE), *Benchmark Test for Seismic Analysis of Steel Structures and Improvement of Seismic Design Methodology*. Tokyo: Steel Structure Committee, JSCE (2000) (in Japanese).
3. Itoh, Y., Ultimate Strength Variations of Structural Steel Members. Doctoral Dissertation, Department of Civil Engineering, Nagoya University, Nagoya, Japan (1984).
4. Itoh, Y., Usami, T. and Fukumoto, Y., Experimental and numerical analysis database on structural stability. *Engng. Structures*, 18, **10**, 812-820 (1996).
5. Itoh, Y., Ishiyama, T., Liu, C. and Fukumoto, H., Database for structural steel experiments under a distributed collaboration environment. *Proc. 1st Inter. Conf. on Advances in Experimental Structural Engng.*, Nagoya, Japan, 773-780 (2005).
6. Golias, M., Angelides, D., Marnas, S. and Vrakas, D., Use of multimedia and the World Wide Web in civil engineering learning. *J. of Professional Issues in Engng. Educ. and Practice*, 131, **2**, 129-137 (2005).
7. Eward, H. and Page, G., Performing experiments by remote control using the Internet. *Global J. of Engng. Educ.*, 4, **3**, 287-292 (2000).
8. Mann, H. and Sevcenko, M., Simulation and virtual lab experiments across the Internet. *Proc. of Inter. Conf. of Engng. Educ.*, Valencia, Spain, 1-8 (2003).
9. Liu, C., Pun, S-K. and Langston, C., A preliminary study on building demolition engineering and management. *World Trans. on Engng. and Technology Educ.*, 4, **2**, 201-207 (2005).
10. East, E., Kirby, J. and Perez, G., Improved design review through Web collaboration. *J. of Management in Engng.*, 20, **2**, 51-55 (2004).
11. Seneviratne, I., Schexnayder, C. and Wiezel, A., Establishing a World Wide Web presence. *Practice Periodical on Structural Design and Construction*, 4, **2**, 69-74 (1999).
12. The Dublin Core Metadata Initiative (2005), http://purl.oclc.org/dc/
13. Japan Road Association (JRA). *Specifications of Highway Bridges*. Tokyo (2000) (in Japanese).
14. Kumar, S., Itoh, Y., Saizuka, K. and Usami, T., Pseudodynamic testing of scaled models. *J. of Structural Engng.*, 123, **4**, 524-526 (1997).