자바 모니터링 서버를 이용한 면진교량의 온라인 네트워크 유사동적 실험

ON-LINE PSEUDO-DYNAMIC NETWORK TESTING ON BASE-ISOLATED BRIDGE USING WEB-BASED JAVA MONITORING SYSTEM

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Abstract

본 논문에서는 한국과 일본에 위치한 여러 연구기관들 사이에서 수행된 온라인 네트워크 유사동적 실험 결과에 대해 나타내었다. 예제 구조물로는 4경간 연속의 면진 교량을 이용하였다. 실험 장비를 보유하고 있는 두 연구기관에서 면진 장치의 비선형 거동에 대한 실험을 수행하고 각 실험 결과를 조합하여 전체 구조의 동적 해석을 수행하였다. 본 논문에서는 먼저 인터넷을 이용한 두 가지 데이터 전송기법을 이용하여 두 기법의 효율성을 비교, 분석하였다. 또한 최근 국내에 위치한 두 연구기관 사이에서 수행된 실험 결과에 대해 논의하였다. 본 연구에서는 상대 연구기관의 실험 상황 및 수행된 실험 결과의 효율적인 모니터링을 위하여 웹 기반의 자바 모니터링 시스템을 개발하였다. 마지막으로 유선과 무선 인터넷을 이용한 온라인 실험 기법에 대하여 나타내었다. 그 결과, 온라인 네트워크 실험에 소요된 실험 시간은 데이터 전송 기법과 실험장비에 따라 매 시간 단계의 데이터 전송에 0.2-15초, 각 연구기관의 유사동적 실험에 1-10초의 시간이 소요되어 매우 큰 폭으로 변화함을 알 수 있었다. 또한 무선 인터넷을 이용한 온라인 실험의 경우, 뛰어난 이동성과 인터넷 보안성 등과 같은 여러 가지 장점을 가지고 있음을 알 수 있었다.

Keywords : Internet, On-line pseudo-dynamic network test, Data communication schemes, Wireless Internet using mobile phones, Web-based Java monitoring system

1. INTRODUCTION

In the structural design for a large structure, a theoretical seismic analysis alone cannot reflect the actual behavior of the real structure in the nonlinear range unless the constitutive relation is exactly known. Recently semi-analytical method by means of combining analysis with experiments, so-called hybrid testing, has been developed [Nishizawa *et al.*, 1988; Hakuno, 1989; Nakashima *et al.*, 1990]. It has been utilized particularly for the evaluation of nolinear dynamic response of structures, and is also referred as the pseudo-dynamic testing. Furthermore, seismic assessment of a large and complex civil structure becomes increasingly difficult, as the number of the elements subjected to nonlinear behavior increases. As the number of the nonlinear elements increases, the same numbers of actuators are generally required to control the displacement of each element for the pseudo-dynamic testing. Therefore, more efficient testing method for large structural systems needs to be developed for the estimation of the seismic capacity. The concept of the on-line network testing using Internet was originated by Prof. Watanabe [Watanabe, et. al, 1999]. The idea seems attractive particularly for pseudo-dynamic testing of complex structural systems with many components subjected to severe nonlinear behavior, which requires many sets of expensive structural testing equipments. Series of the previous studies among Kyoto University (KU), Osaka City University (OCU), and Korea Advanced Institute of Science and Technology (KAIST) showed that computer systems and testing stations which are scattered all over the world can be interconnected and used interactively by the remote control owing to the recent development of the worldwide scale of the Internet. [Watanabe *et al.*, 1996; Nagata *et al*, 1998; Watanabe *et al.*, 1999; Yun *et al*,2000]

In this study, on-line pseudo-dynamic network testings were carried out on base-isolated bridges with multiple piers. Test facilities located at two institutions were interactively used to test the nonlinear behavior of the base-isolators, and the measured nonlinear restoring forces were fed back to the main computer to calculate the

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response of the entire system including the base-isolators at the next time step. Two different data communication schemes were used and their efficiency was compared. Wireless Internet communication using mobile phones was also investigated, and the advantages were discussed.

2. GENERAL CONFIGURATIONS AND DATA COMMUNICATION SCHEMES

The general configuration of the on-line pseudo-dynamic network testing system using Internet is depicted in Figure 1. It consists of a main computer system and several local server / experiment systems. The main computer contains an analysis engine for dynamic analysis of the entire structural system and a main client system for controlling the local server / experiment systems. At each time step, firstly, the response analysis is carried out to obtain the target displacements of the test specimens at the next step using the analysis engine in the main computer by referring to the restoring forces measured by the testing facilities independently in the previous step. The computed target displacements are transferred through the Internet and fed into the local servers. Then each local server controls the test equipment on each test specimen to obtain the restoring force corresponding to the imposed displacement, and the result is sent back to the main system. Then the dynamic response analysis proceeds to the next time step.

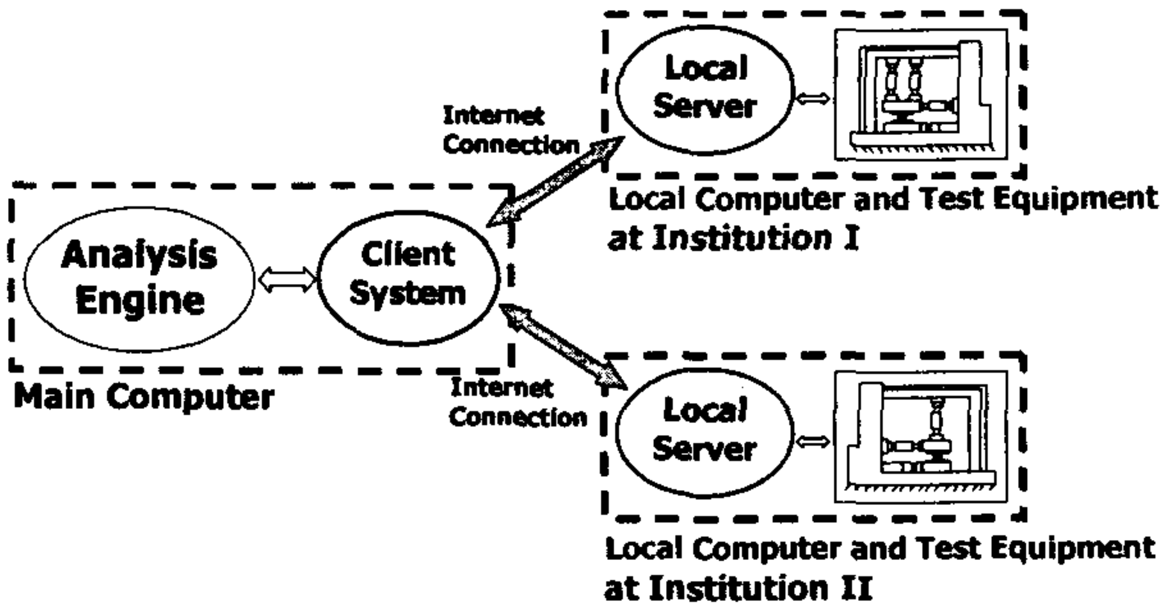


Figure 1 On-line Pseudo-dynamic Network Testing System

Special schemes are required for data communication between the main system and local servers, and also between each local server and the test equipment. Two system configurations, I and II, with different data communication schemes were used in this study. Configuration I originally developed by Kyoto University [Watanabe *et al.*, 1996] basically consists of engineering workstations (EWS) for the main system and local servers with Unix operating systems as in Figure 2. Data communications between the main and local systems through Internet were carried out using the well-known TCP/IP (Transmission Control Protocol / Internet Protocol) protocol [Nielson, et al. 2001]. But data communication between the local server and the personal computer (PC) which controlled the test equipment was carried out using a general purpose SAMBA program [Sharpe, et al. 2000]. The PC was operated using Windows operating System. SAMBA program was required to share the displacement and restoring force files between the EWS and PC, which used different operating systems.

Configuration II developed later by KAIST [Yun *et al.*, 2000] is composed of PCs for the main and local server systems with Windows operating system as in Figure 3. Data communications between the main and local server systems through Internet were carried out using TCP/IP protocol as in Configuration I. However, additional PCs are not needed, since the local server directly controlled the test equipment. SAMBA program is not required for sharing the displacement and restoring force between the EWS and PC which controls the testing equipment. Furthermore, during the data transmission, it is not required to convert the displacement and restoring force data to file type, since the communication is performed using the packet type. Therefore it is expected to reduce the data communication time between the client and local server systems considerably. In this configuration, the network programming and the analysis engine for dynamic analysis of the entire structural system were written using the Visual C++ language.

Figure 4 shows the test equipments with the LRB specimens for a base-isolated bridge model at two institutions. The pseudo-dynamic test equipment at KU is a multi-directional system with 2 translational and 1 rotational deformations, while the one at KAIST is a simple uni-directional system. The test operations were monitored by each other using web-cameras.

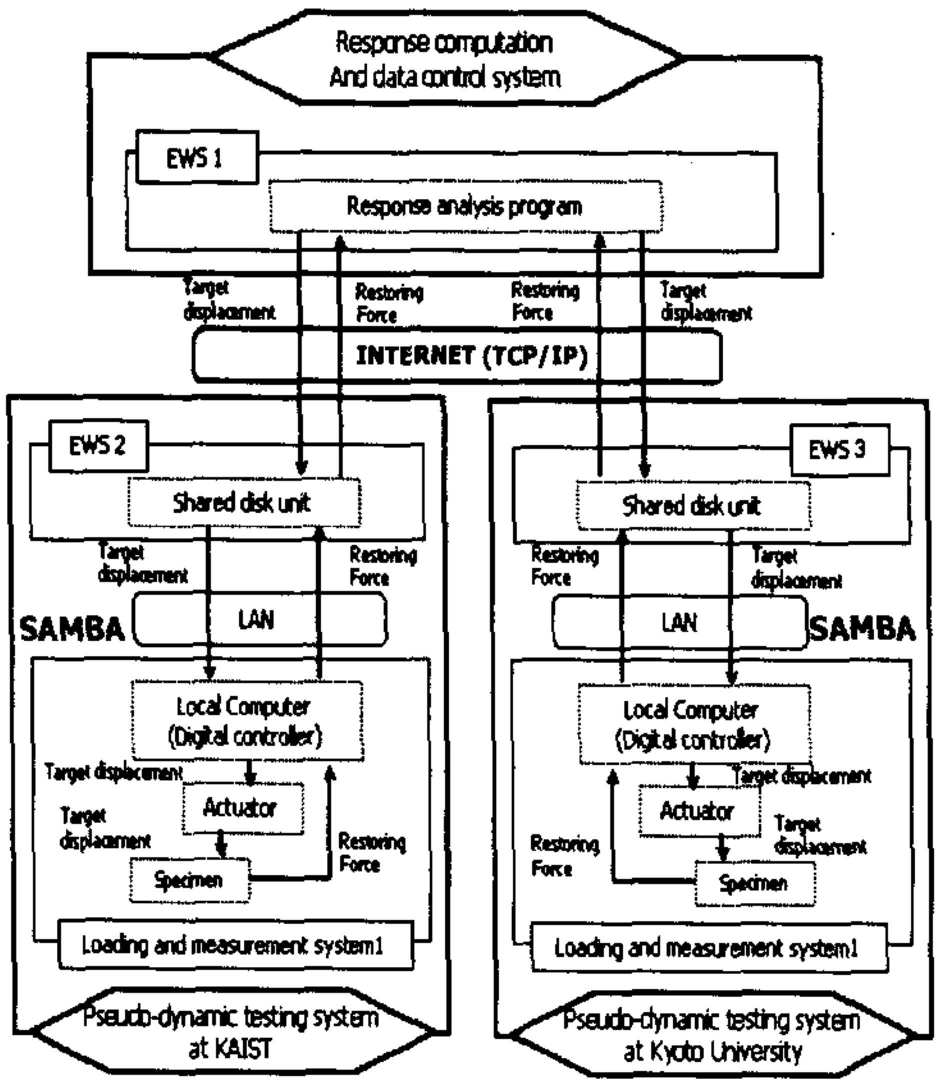


Figure 2 Configuration I (Using TCP/IP and SAMBA)

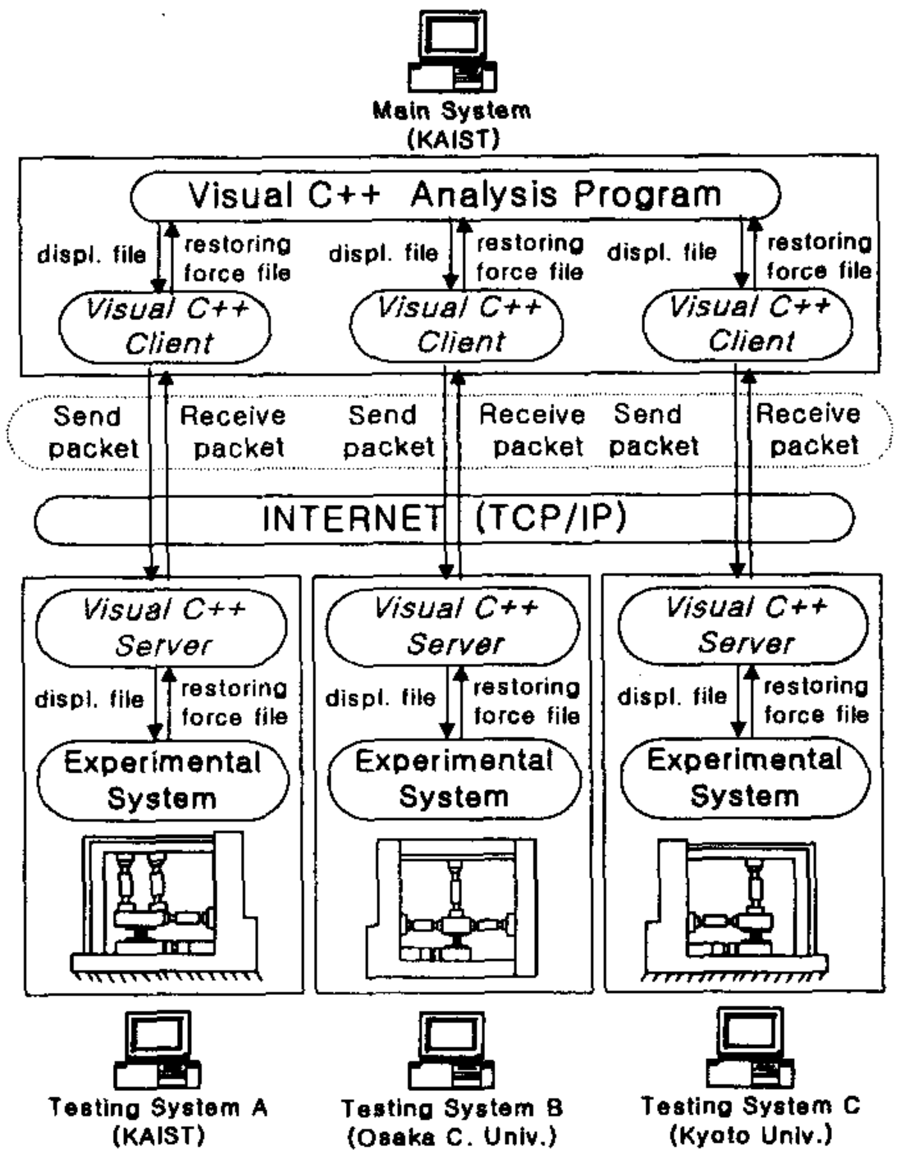
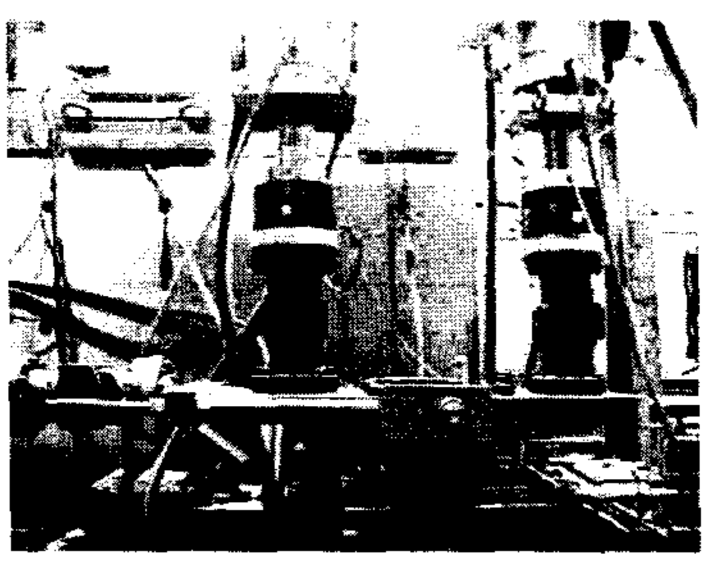
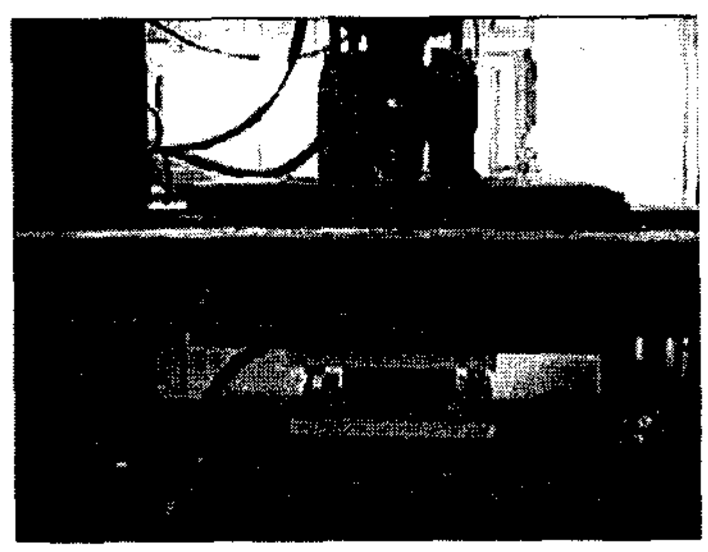


Figure 3 Configuration II (Using TCP/IP)



(a) at Kyoto University



(b) at KAIST

Figure 4 Testing Facilities with LRB Specimens

Table 1 Elapsed Time for Remote On-line Testings

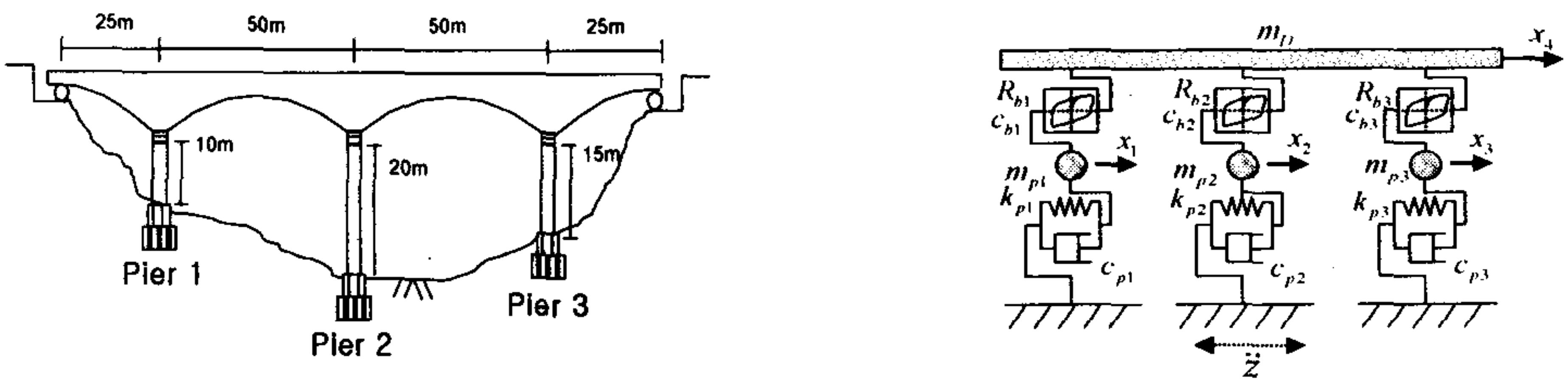
Communication Schemes	*Main System*	*Sub-Systems*	*Elapsed Time*		*Remarks*
			1000 step	*per step*	
TCP/IP and SAMBA	Kyoto Univ.	KAIST, OCU	418.3 min	25.1 sec	Tests at KU & KAIST and Analysis at OCU
		KAIST, OCU	250.0 min	15.0 sec	Analysis
TCP/IP only	KAIST	KU, KAIST	200.0 min	12.0 sec	Tests at KU & KAIST and Analysis at KU
		KU, KAIST	17.0 min	1.02 sec	Test at KAIST and analyses at KU
		KU, KAIST	4.2 min	0.25 sec	Analysis

The elapsed time of the on-line experiments previously carried out on a base-isolated bridge among KU,OCU, and KAIST using two different system configurations was summarized in Table 1. The base-isolators on Piers 1 and 2 were tested at KU and KAIST, respectively, while the test on the base-isolator on Pier 3was replaced by a simulation analysis at OCU. It took about 25sec per time step using Configuration I, which seems to be fairly long. A parallel analysis was also carried out by replacing all the tests by computer simulation analyses to estimate the data communication time. The results indicate that it took about 15sec for data communication through Internet, and 10sec for actual pseudo-dynamic test for each time step. The above results indicate that the data communication scheme via SAMBA took fairly long time. It may be caused by the fact that SAMBA was written for too much general purpose. Similar testings were carried out on the same bridge system using Configuration II based on TCP/IP only. At first tests were carried out at KU and KAIST, while the test at OCU was replaced by a simulated analysis. In this case, it took about 12sec for each step, which is much shorter than the previous case using Configuration I. Then actual test was carried out only on LRB 2 at KAIST, while the tests on LRBs 1 and 3 were replaced by simulation analyses at KU and OCU. The elapsed time was found to be about 1sec for each step in this case. The big difference in the elapsed time for 2 above cases was caused by the long execution time of the test equipment at KU, which is a multi-directional system. If the test on LRB 2 was also replaced by a simulation analysis at KAIST, it took only 0.25sec for each step, which is mainly for the data communication through Internet.

3. ON-LINE NETWORK TESTING BETWEEN KAIST AND KIMM

3.1 Example Structure

Example study between KAIST and Korea Institute of Machinery and Materials (KIMM) was performed on a concrete box girder bridge model with 4 continuous spans as shown in Figure 5(a). Rubber bearings (RB) are assumed to be installed at the tops of three piers with different heights. All of the piers assumed to be made of steel. An idealized model which consists of four degrees-of-freedom for earthquake loads in the longitudinal direction is shown in Figure 5(b), and the structural properties are listed in Table 2. The idealized model consists of 4 concentrated masses for a deck and 3 piers (m_D and m_{pi}), 3 linear stiffness elements for piers (k_{pi}), and 3 nonlinear elements for RBs. For the bridge with a conventional bearing arrangement (i.e. one hinge on Pier 2 and rollers on Piers 1 and 3), the primary natural period is obtained as 0.87 sec in the longitudinal direction, that locates at the period range with high spectral acceleration. RB bearings installed on the piers are designed to lengthen the primary effective natural period to 2.0 sec. In this study, El Centro earthquake record (NS, 1940) with the maximum peak ground acceleration adjusted to 0.2g was used as an input earthquake in the longitudinal direction. Figure 6 shows the acceleration time history and response spectrum (5% damping). It can be noticed that the spectral acceleration significantly decreases, as the natural period increases owing to the RBs.



(a) Example Structure (b) Analysis Model

Figure 5 Example Bridge with Base-isolators and Its Analysis Model

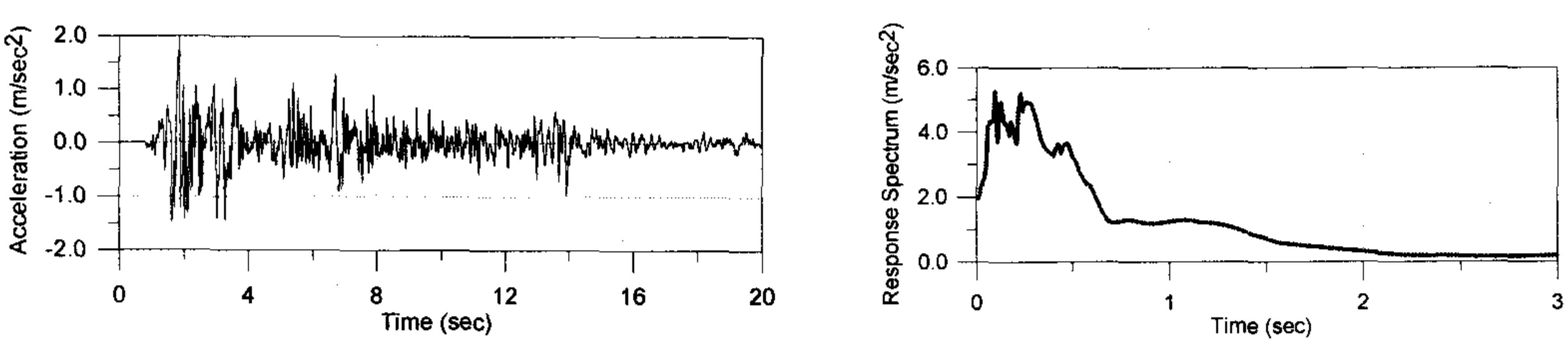


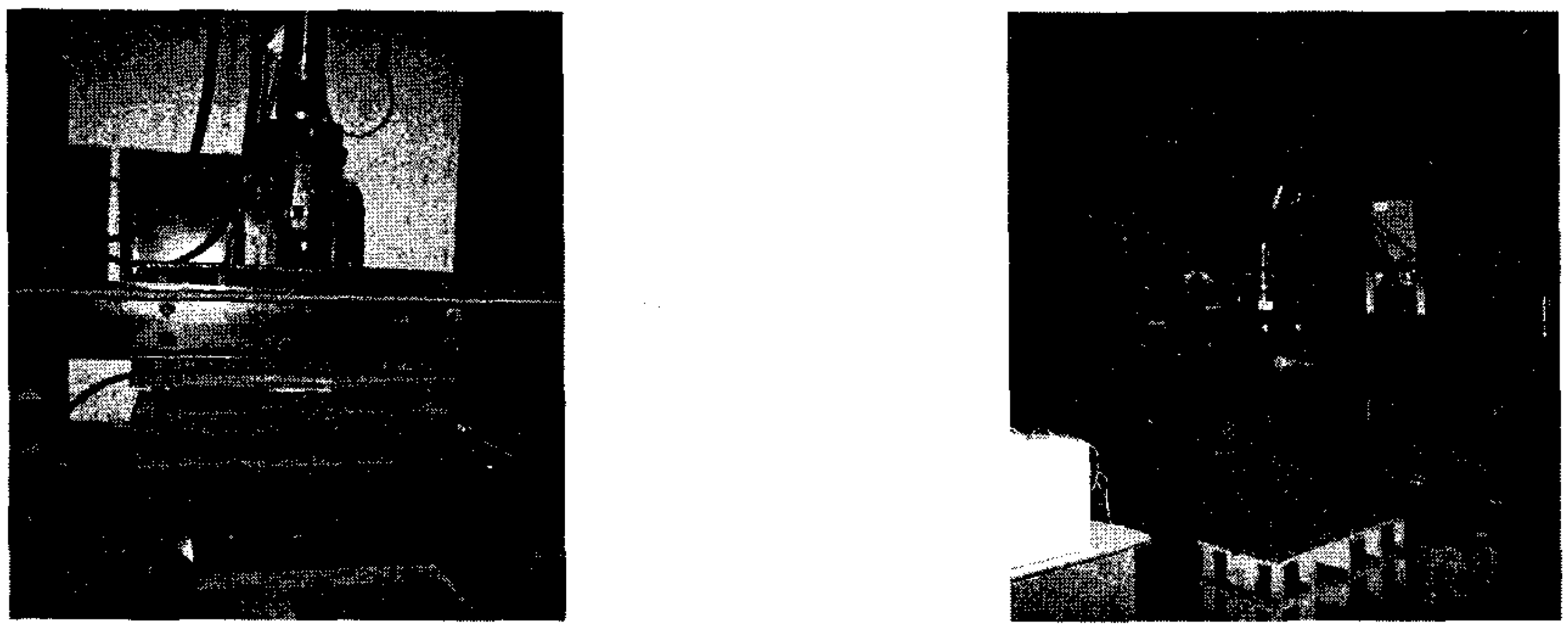
Figure 6 Input Earthquake Acceleration and Response Spectra: El Centro 1940 (pga=0.2g)

Table 2 Structural Characteristics of Example Bridge

	Pier 1	*Pier 2*	*Pier 3*	*Deck*
Stiffness (kN/m)	3.44×10^5	8.60×10^4	1.38×10^5	∞
Weight (kN)	6.46×10^2	1.29×10^3	9.80×10^2	3.2×10^4
Natural Period of Bridge (sec)	0.82* (2.0**)			

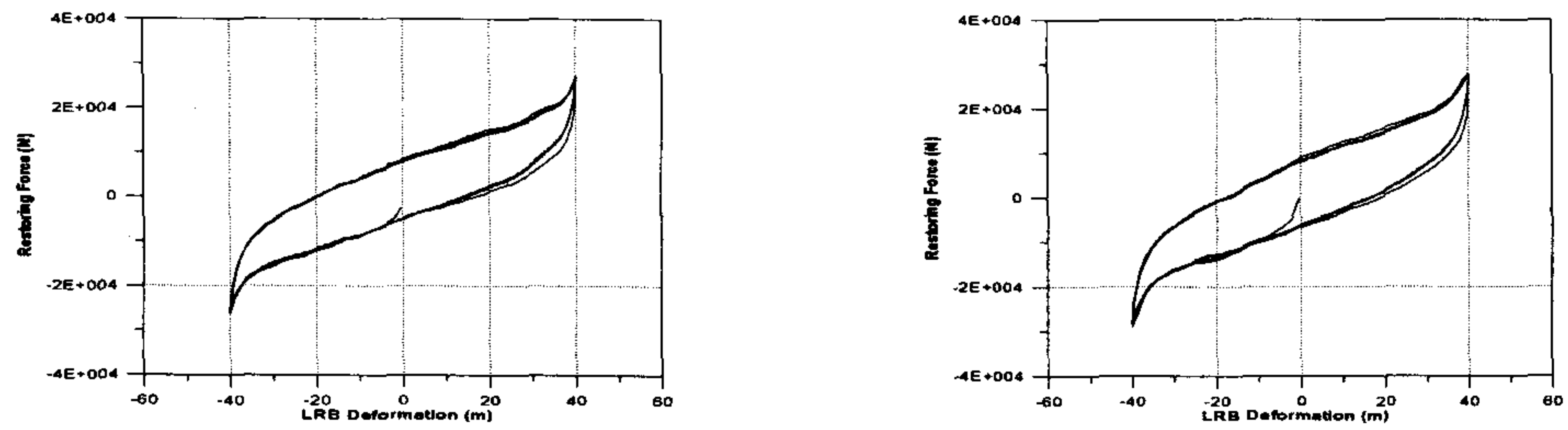
3.2 Preliminary Tests

Before performing on-line pseudo-dynamic testing for earthquake input motion, cyclic loading tests were performed on RB specimens of 1/3 scale at KAIST and KIMM. Figure 7 shows the test equipments with the RB specimens. Both of the testing equipments are uni-directional testing systems. So, loading time on the RBs for earthquake load is relatively short. It is assumed that 8 units of the prototype RBs are installed on each pier. The vertical load on an RB specimen is 367.5 kN. The loading is applied in a horizontal plane and the maximum displacement is 4 cm, which corresponds to the shearing strain of 54% for thickness of RB's rubber layer. The loading was performed to have the following sequence of displacements ; ±1, ±2, ±3 and ±4cm. Figure 8 shows the hystereses of the specimens at two institutions.



(a) at KAIST (b) at KIMM

Fig. 7 Testing Facilities



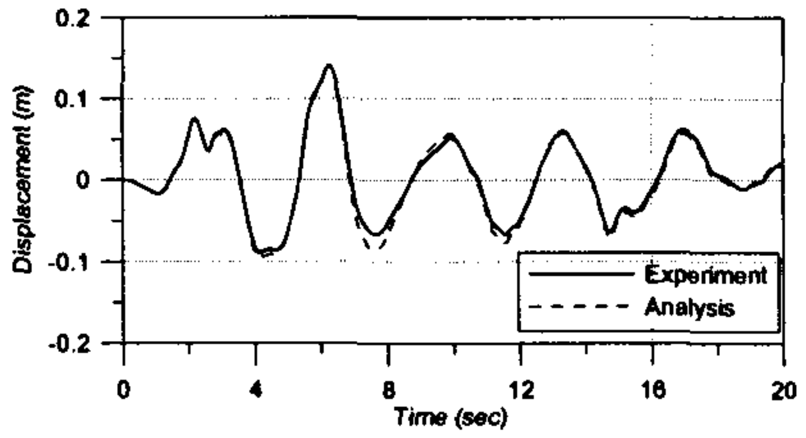
(a) RB 1 at KAIST (b) RB 2 at KIMM

Fig. 8 Hystereses for Cyclic Tests on RB Specimens

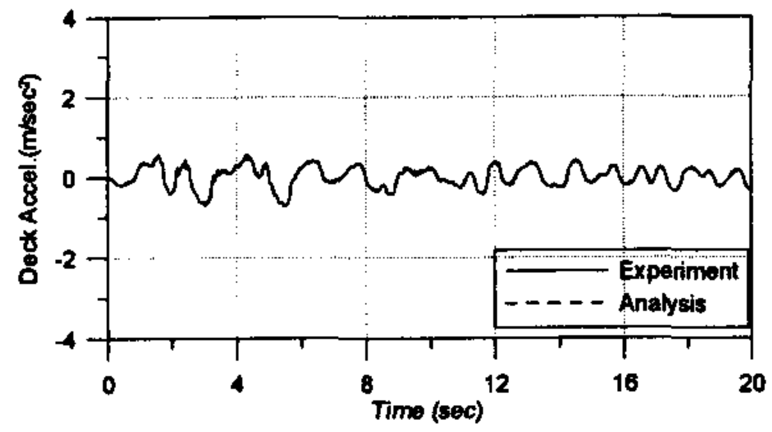
3.3 Results of on-line Pseudo-Dynamic Testing

The results of the pseudo-dynamic tests are shown in the Figure 9. They are the displacement and acceleration of the deck and the hystereses of 2 RB specimens at the piers. Earthquake response analysis was also performed for the purpose of comparison. Performing analysis, the experiments of pier 1 and 2 are replaced by idealized bi-linear curves determined from the preliminary cyclic loading test. The testing results are plotted along with the analysis results. Maximum deck displacement is about 0.14m which is almost same to the analysis result. The maximum total deck acceleration is found to be 0.073g, which is considerably smaller than the peak ground acceleration (0.2g). This is caused by the base isolation and additional damping effects of the RBs. From Figures 9 (c)-(e), the hysteresis curves during the on-line network testing are found to be very similar to the analysis results. However, the restoring force measured by the local cell inside of the horizontal actuator at KIMM shows considerable noise, which may be caused by the vibration effect of the mass moving with the actuator during the pseudo-dynamic test. The test equipment at KAIST has another load cell underneath of the RB, so the effect of the moving mass may be reduced.

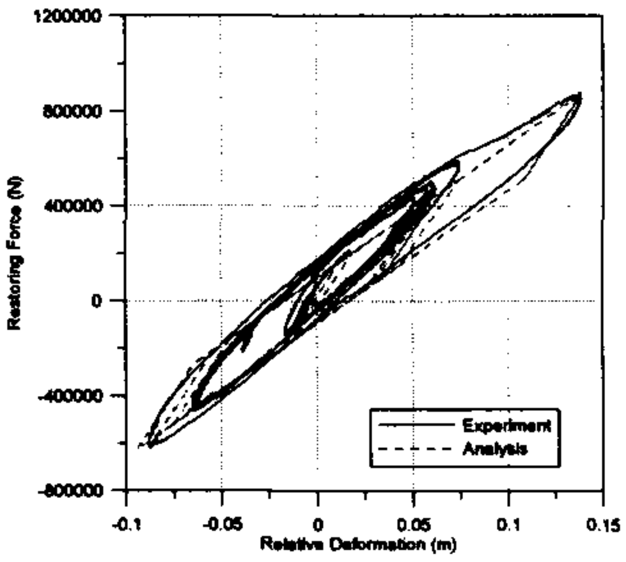
The elapsed time for the on-line testing is summarized in Table 3. In this test, the main client system was located at KAIST and local server systems for the experiments were located at KAIST and KIMM. RB specimens on Piers 1 and 2 were tested at KAIST and KIMM respectively, while the behavior of the RB on the Pier 3 was obtained through a simulation analysis at KAIST. For the entire on-line network testing, it took about 69minutes for 4000 time steps, namely, about 1.04sec for each time step. It took about 0.2sec for each time step, if all of the tests on the base-isolators were replaced by on-line simulation analyses at KAIST. The elapsed time for the present tests between KAIST and KIMM is almost same to the time required between KAIST and KU in Table 2. This result indicates that the data communication time over the sea through Internet is almost negligible to the total elapsed time for the on-line pseudo-dynamic network test.



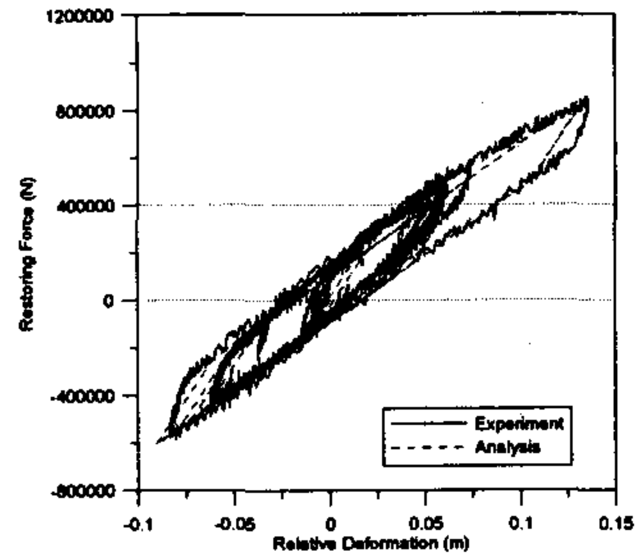
(a) Deck Displacement



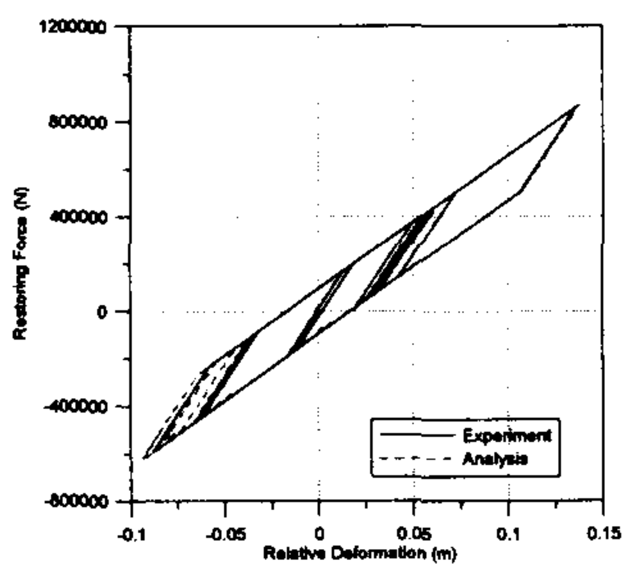
(b) Total Deck Acceleration



(c) Hysteresis of RB 1: KAIST



(d) Hysteresis of RB 2: KIMM



(e) Hysteresis of RB 3: Simulation

Fig. 9 Results of On-line Network Testings

4. ON-LINE NETWORK TESTS THROUGH WIRELESS INTERNET USING MOBILE PHONES

4.1 Concept of Wireless Internet

The feasibility of the wireless Internet technology for the on-line network testing was investigated. Mobile phones were used for wireless Internet communications between the laptop computers controlling the test facilities and the wireless application protocol (WAP) gateways which are connected to Internet servers at two participating institutions. The communication schemes using only TCP/IP without SAMBA program were used for the on-line testing. In this case, WAP protocol was used for Internet access. WAP technology has been widely used for information delivery to thin-client devices, such as mobile phones. The Figure 10 shows the basic structure of the on-line network testing through two wireless communications using mobile phones. The laptop computer can be allocated a dynamic IP address by the wireless Internet between mobile device and WAP gateways. Each WAP gateways are connected to Internet servers and work as a general Internet through wire. Merits and demerits of two methods of Internet connection are summarized in Table 4. At first, wireless Internet has relatively low speed for data transmission (64kbps-2mbps) and higher cost than Internet through wire. But, data transmission speed is good enough for our scheme, since our data size during the test of each step is very small. And also the cost of the wireless communication by mobile phone has been found to be reasonable ; i.e. about $20 for a on-line testing for 4000 time steps between two institutions in Korea. As wireless Internet technologies develop further, the data transmitting speed will become faster and the cost will be reduced further. The wireless Internet has various advantages for online network testings; e.g., excellent mobility and good Internet security using the encryption of data for communication. It may be conveniently used to build a temporary wireless Internet connection between the main and a local server system during a network test, particularly if the local server is located at an institution with a very rigid firewall in the computer system. Even in this case, the established wireless Internet connection is completely independent of the existing network systems, so the computer systems at the participating institutions can be secured from the unauthorized intruders.

Table 3 Elapsed Time

Communication Schemes	*Main System*	*Sub-Systems*	*Elapsed Time*		*Operations*
			1000 step	*per step*	
TCP/IP only	KAIST	KAIST KIMM	17.25 min	1.04 sec	Test
TCP/IP only	KAIST	KAIST	3.33 min	0.2 sec	Analysis

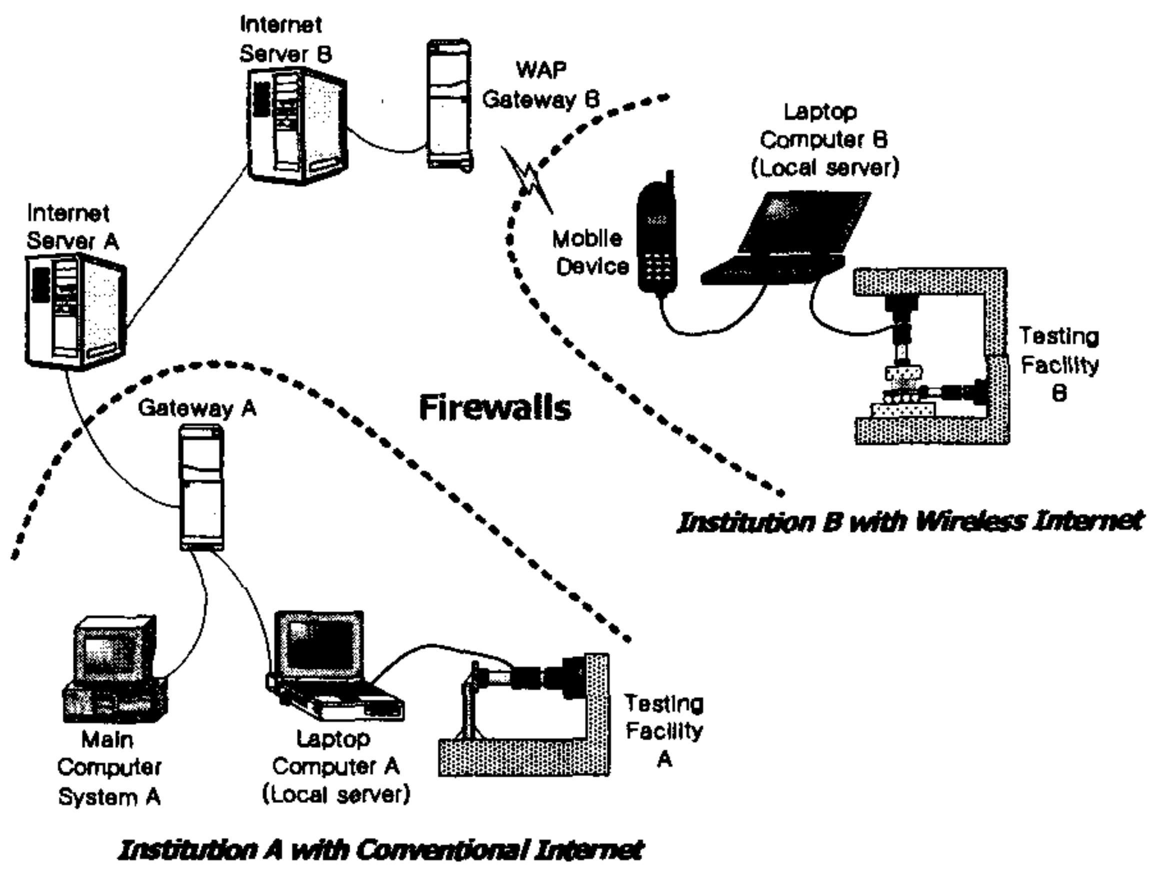


Fig. 10 On-line Network Testing through Wireless Internet Using Mobile Phones

Table 4 Internet through Wire vs Wireless Internet

	Internet through Wire	*Wireless Internet*
Protocol	* TCP/IP	* TCP/IP
IP Allocation	* Fixed IP or Dynamic IP	* Dynamic IP
Merits	* high speed * economic data communication charge * good for P2P communication with fixed IP * stable communication	* excellent mobility * needs no communication equipments * good Internet security using encryption * bypassing capability of the firewall
Demerits	* less mobility * needs firewall for Internet security	* relatively high cost * disadvantage for P2P communication * relatively low speed

4.2 Result of Simulation Study

The elapsed time of the simulation analysis using Internet and wireless Internet are compared in Table 5. The results indicate that the elapsed time for data communication is 0.2sec for each time step by the conventional Internet through wire and 0.38sec by the wireless Internet by mobile phone. The elapsed time for both cases is much shorter than the time required for the pseudo-dynamic testing. So, it may be concluded that wireless Internet using mobile phone is a very attractive and effective method for on-line network testings.

Table 5 Elapsed Time

Communication Schemes	*Main System*	*Sub-Systems*	*Elapsed Time*		*Operations*
			1000 step	*per step*	
TCP/IP & Internet	KAIST	KAIST	3.33 min	0.2 sec	Analysis
TCP/IP & Wireless Internet	KAIST	KAIST	6.33 min	0.38 sec	Analysis

5. WEB-BASED JAVA MONITORING SYSTEM

During the on-line network test, it is very important to monitor the test operations and results among the test participants, since the experiments are carried out interactively among the geographically distributed participating institutions. A web-based Java monitoring system was developed for effective monitoring and sharing of the test results. A terminal server using Java language was added to the connection between the main and local computers as in Figure 11. The Java terminal server was used for checking the packet data and time of transmitting at each step. It also sends the certified results to the Java web server for monitoring among the participants and guest observers. All of the participants and observers can monitor the testing operations and share the test results. Figure 12 shows the scheme of on-line monitoring system using web cameras in this study.

Telepresence system was provided in the Java based monitoring system. Hence on the web-based interface, remote login, observation, and remote control operation for testing facilities are possible to the test participants. The participants do not need to be in front of the local server computers connected to the main client computer to operate the system. They can start the on-line network testing anywhere by using any kind of computer system, if they know the authorized login ID, password, and the IP address of the local server computer system. Java runs on most of the major hardware and software platforms, including Winodws 2000 and XP, the Mac OS, and several variations of UNIX, hence no recompilation or re-coding is required with Java-based program though the OS changes. They can monitor the test operations and results of any test partner, and exchange the opinion about the test.

Figure 13 shows an example window of the on-line network testing. The left part of the screen shows the digitized test results of packet number (step number), displacement, restoring force and delay time at each time step. And the right part shows the hysteresis loop, time histories of restoring force and displacement of the specimen, and time delay at each time step during the network connection.

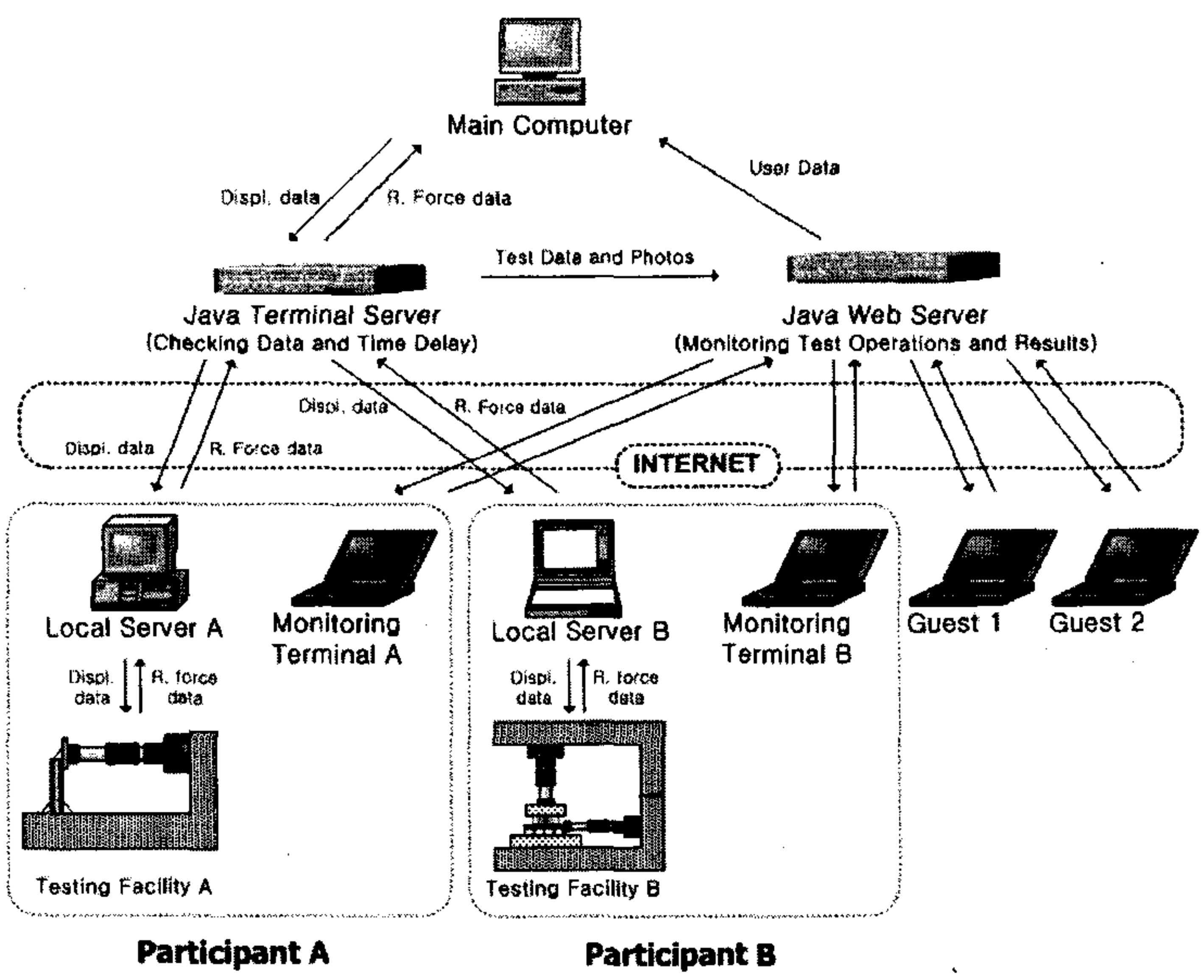


Figure 11 Web-based Java Monitoring System

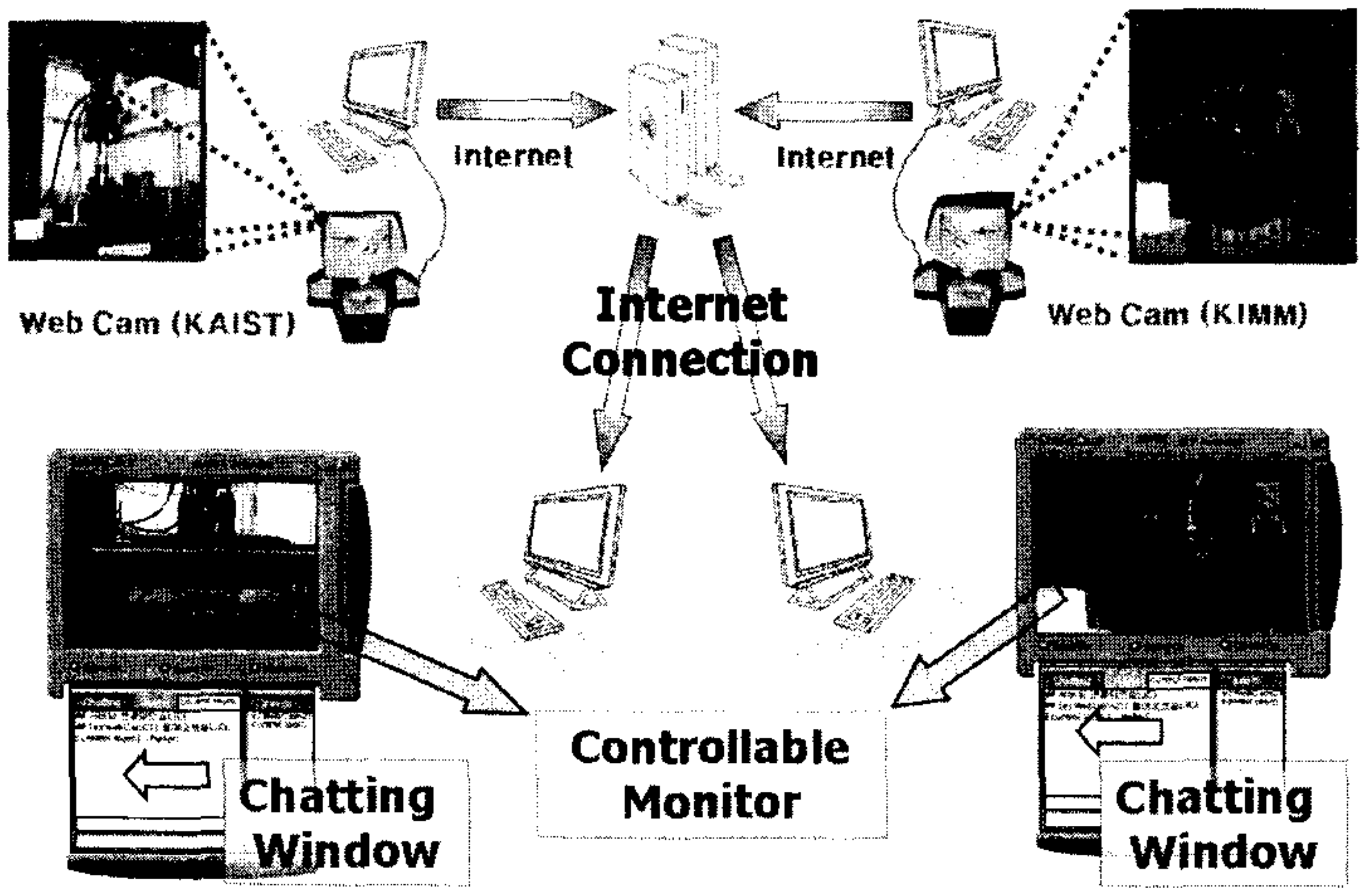


Figure 12 On-line Monitoring System Using Web Cameras

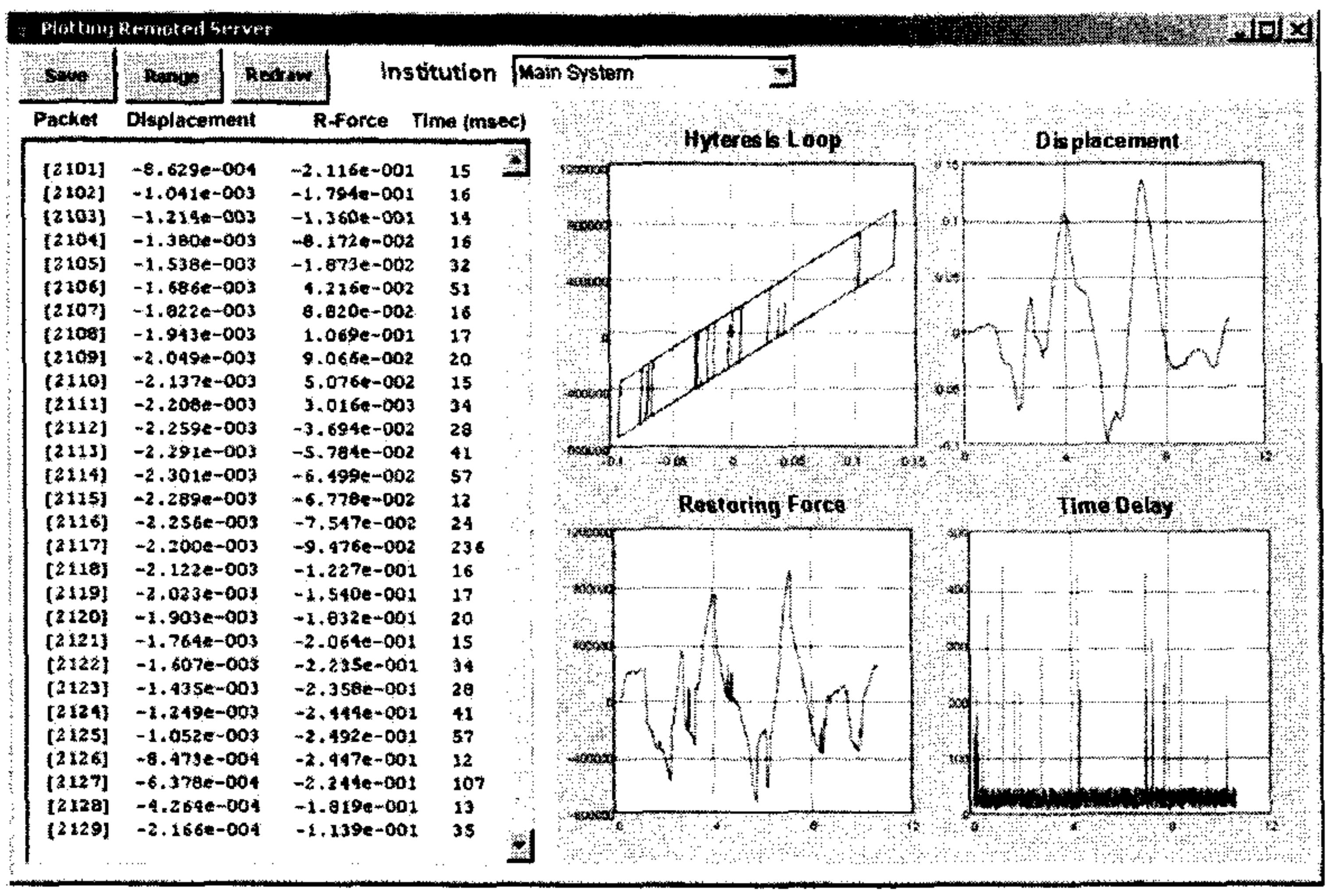


Figure 13 Example Window of Java Monitoring System

6. CONCLUSIONS

In this study, on-line pseudo-dynamic network tests were conducted among several institutions in Korea and Japan using various data communication methods through the Internet. The conclusions from this study can be summarized as follows :

1) On-line network pseudo-dynamic testing using the Internet is very feasible in view of the fact that may testing facilities at different locations can form a network for interactive testings for large and complex structural systems.

2) The time required for each step in the on-line testing varies widely depending on the data communication schemes and the testing hardware : i.e. 0.2-15sec for data communication and 1-10sec for execution of pseudo-dynamic test for each time step.

3) Configuration II which consists of all PCs and uses TCP/IP-based data communication scheme has been found to be much more efficient than Configuration I which is composed of EWSs and PCs and requires SAMBA program for data sharing between the local servers (EWSs) and the PCs. Furthermore, the parallel data communication scheme used in Configuration II is found to be very effiective to reduce the elapsed time.

4) Web-based Java monitoring system was found to be very convenient and effective for detailed checking of

partners' testing condition and for sharing of the test results among the test participants and authorized observers. The telepresence system can be provided by using the web-based Java monitoring system.

5) Wireless communication using mobile telephone technology is very attractive for on-line network testings, owing to the mobility and the Internet security. The time required for data communication is about 0.4 sec per each time step, which is still reasonable for pseudo-dynamic tests. The wireless Internet may be used for temporary connections between the main and a local server system during the network test without causing any security problem to the existing computer systems at the participating institutions, particularly if the local server is located at an institution with a very rigid firewall. Furthermore, wireless Internet technology may provide the data encryption to all of displacement and restoring force data.

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