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REMOTE PARALLEL TESTING USING INTERNET ON BASE ISOLATED BRIDGE

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Abstract

This paper presents a numerical simulation study for remote parallel pseudo-dynamic testing using Internet on base isolated bridges. In this testing method, experimental facilities located at different places can be parallelly used for testing a large-scale structure with many components subjected to severe nonlinear behavior. Example analysis is carried out on a base-isolated bridge for earthquake loading. The results indicate that it takes about 35mintes for data communication between four facilities located about 250km apart through Internet for 4000 time steps, which is fairly equivalent to the time required for pseudo-dynamic testing. This testing method can become more powerful, as the data communication technique through Internet improves.

Introduction

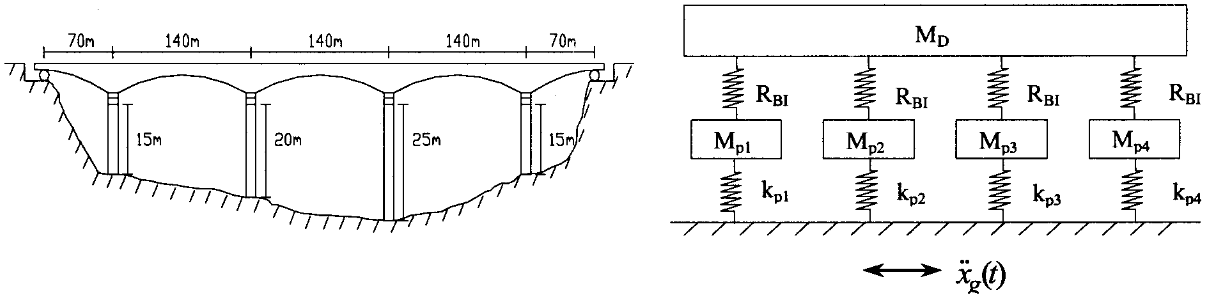
The concept of the parallel testing remotely controlled using Internet was originated by Prof. Watanabe[Watanabe, et. al, 1999]. The idea seems very attractive for multiple pseudo-dynamic testing[Shing, et. al, 1984, Chung, et. al, 1999] of a complex structural system with number of components subjected to severe nonlinear behavior, which requires many sets of expensive structural testing equipments.

Prior to the joint experiments with Prof. Watanabe at Kyoto University, Japan through Internet, a preliminary study has been carried out by connecting four computer systems located at KAIST, Yosu University and Changwon University, which are located about 250km apart in Korea. The example structure is a continuous concrete box girder bridge with base-isolators at the tops of four concrete piers with different height. The total length of the bridge is 560m.

As a preliminary study, four cases with different bridge bearings are considered. One is the ordinary case with a hinge support at the top of the 2nd pier from the left and roller supports at the others, and the other cases are those with shock transmission units (STU), lead rubber bearings (LRB), and hysteretic damping bearings with STU's (PNuD), respectively. In this study, testing on the base-isolators are not physically carried out, but they are replaced by computer simulations on the bridge bearings with the assumed hysteretic characteristics. From the analysis, it has been found that it takes about 35minutes for data communication between four computers located about 250 km apart through internet for 4000 integration time steps, which is fairly equivalent to the time required for pseudo-dynamic testing.

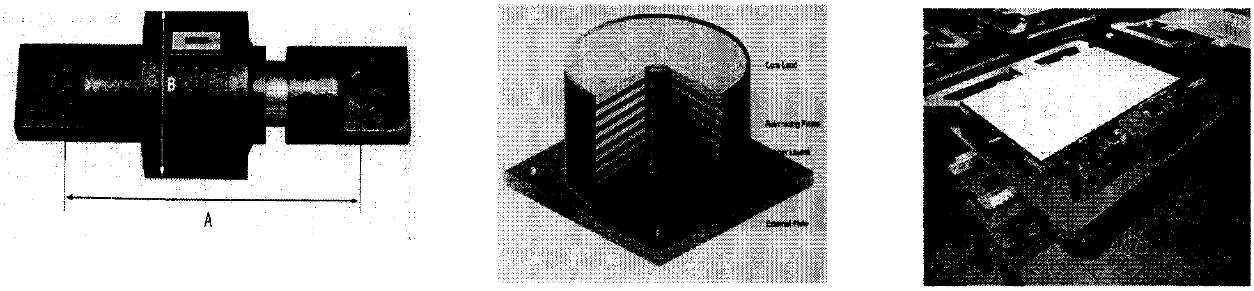
Example structure with various bridge bearings

Numerical simulation study was performed for a concrete box girder bridge with 5 continuous spans. Four cases with different bridge bearings installed at the tops of four concrete piers with different height are investigated. The structure and its idealized model for earthquake response analysis are shown in Figure 1, and the structural properties are in Table 1. Three kinds of aseismic bridge bearings are shown in Figure 2. The idealized model consists of concentrated masses for the deck and piers (M_D and M_{pi}), linear stiffness elements for piers (k_{pi}), and nonlinear elements for restoring forces (R_{BI}) of bearings. The first natural period of the bridge with ordinary bearings in the longitudinal direction is 0.47sec, and the one of the base-isolated case either with LRB's or PNuD's is 2.01sec. El Centro Earthquake record (NS, 1940) of which maximum peak ground acceleration is adjusted in 0.2g has been used for an input earthquake load.



(a) Example Structure (b) Analysis Model

Figure 1 Example Bridge with Base-isolators and Its Analysis Model



(a) STU (b) LRB (c) PNuD

Figure 2 Aseismic Bridge Bearings

Configuration of remote parallel testing through Internet

The configuration of the parallel pseudo-dynamic testing and the way of data communication through Internet are depicted in Figure 3. The main computer at KAIST analyzes the bridge structure based on the reaction forces obtained from on-line pseudo-dynamic tests on four base-isolators. One base-isolator is controlled directly by the main computer, while the others are controlled by the sub-computers located about 250km apart but connected to the main computer through Internet. The maximum data transmitting rate of network is 10Mbps and four computers have almost same capacity (OS: Windows 98, Processor: Pentium III 500MHz, RAM: 512Mbyte). The Visual C++ was used for the main program of structural analysis and the internet program of data transmitting.

Cases	Mass (ton)	Stiffness (kN/m)	Damping (%)
Deck	13,000	Rigid body	0.03
Pier 1	300	6.5*10^5	0.05
Pier 2	400	5.3*10^5	0.05
Pier 3	500	4.5*10^5	0.05
Pier 4	300	6.5*10^5	0.05

Cases	Stiffness(kN/m)			Yield Displ. (cm)
	Initial	After Yielding		
	LRB & PNuD	LRB	PNuD	
Isolator1	1.5*10^5	3.57*10^4	1.6*10^3	1.0
Isolator2	1.5*10^5	3.57*10^4	1.6*10^3	1.0
Isolator3	1.5*10^5	3.57*10^4	1.6*10^3	1.0
Isolator4	1.5*10^5	3.57*10^4	1.6*10^3	1.0

Table 1 Properties of Bridge Model

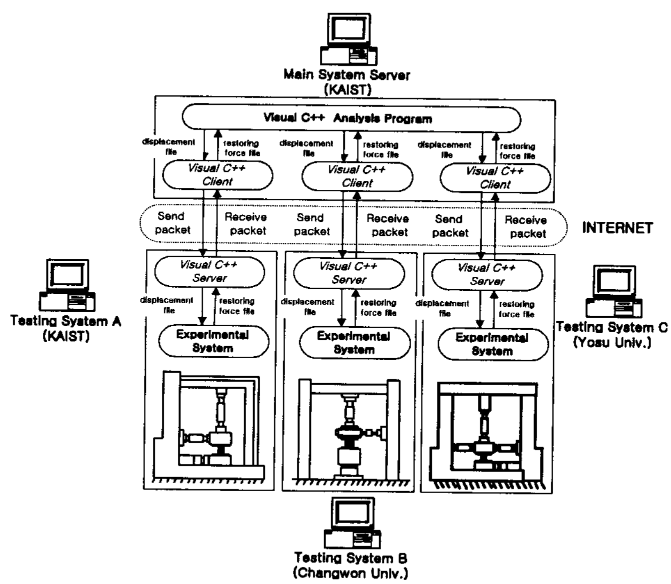


Figure 3 Configuration of Remote Parallel Testing

Results and discussions

For comparison of the data communication time, example analysis were carried out for three different system configurations and the computational time is summarized in Table 2. In the first case, the analysis was performed with four computers located at different locations. On the other hand, in the second case four computers were located at KAIST connected with a local area network system(LAN). In the last case, the entire analysis was performed using one computer. From the result in Table 2, it can be observed that the data communication time between four computers located 250 km apart through internet is about 35minutes for 4000 integration time steps, which is not too grave considering the required time for pseudo-dynamic testing which is approximately estimated as 37minutes for 4000 steps(for instance, 0.5sec per step).

Figures 4-7 and Table 3 show dynamic responses of bridges with different bearing systems subjected to El Centro earthquake record (NS, 1940). Using the base-isolators, the total acceleration of bridge deck was reduced to 30-45% level of the value for the bridge with ordinary bearings. Consequently, the base shears of the piers reduced very significantly. On the other hand, the total acceleration of the bridge with STU's increased to 1.8 times. From the results, it may be concluded that the performance of the PNuD as aseismic bridge bearing is better than the performances of the LRB and the STU.

Table 2 Computation Time

System Configurations			Computation Time	
Main System	Sub-Systems	Connection	4000step	1step
at KAIST	at KAIST, Yosu Univ., and Changwon Univ.	Internet [distance : 250km]	35 min	0.53sec
at KAIST	at KAIST	Internet[LAN]	13min	0.2sec
at KAIST	at KAIST	Using a single computer	0.3 sec	0.75msec

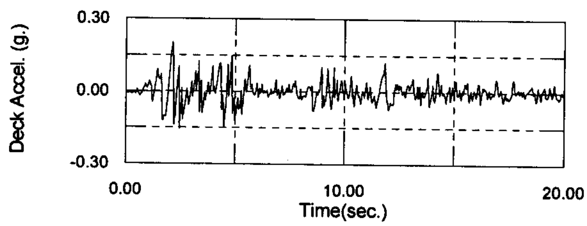
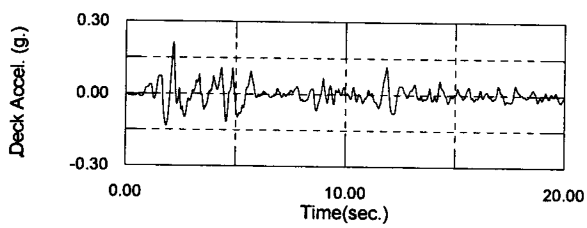
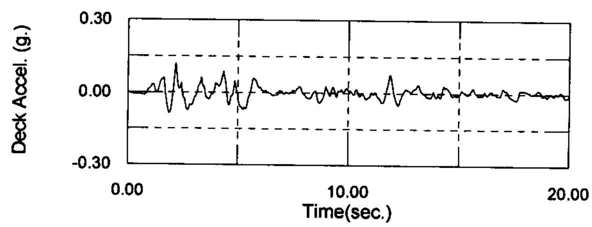


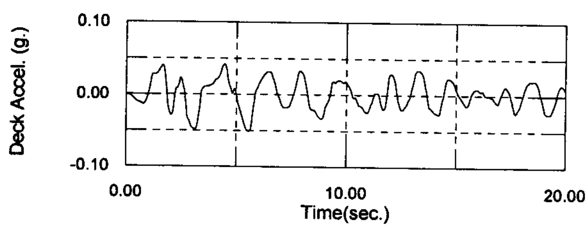
Figure 4 Input Earthquake Record : El Centro 1940 (pga=0.2g)



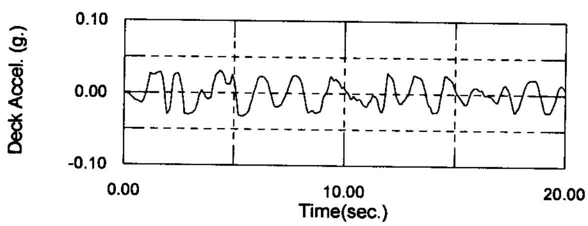
(a) Bridge with ordinary bearings



(b) Bridge with STU's

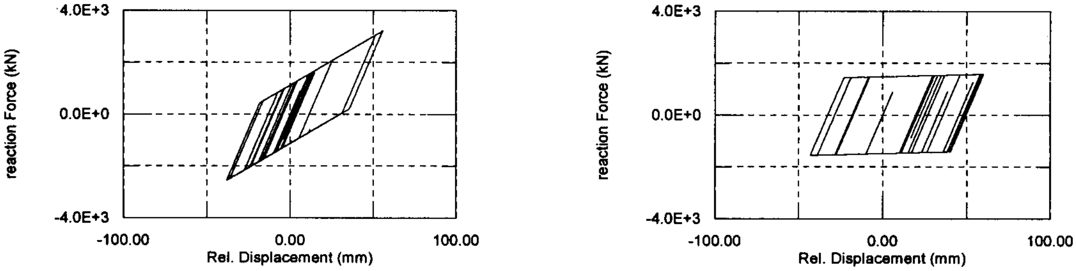


(c) Bridge with LRB's



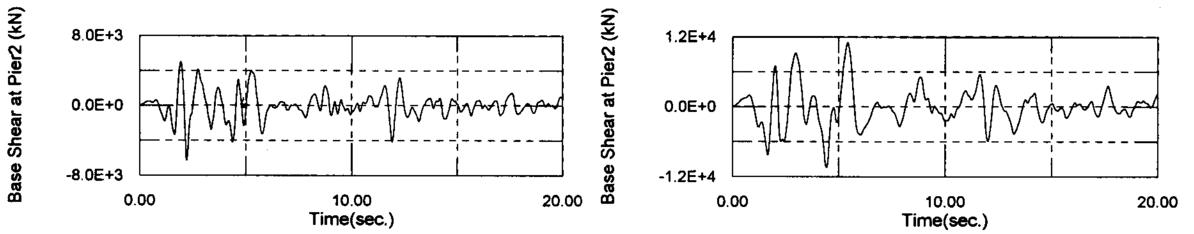
(d) Bridge with PNuD's

Figure 5 Total Acceleration of Deck

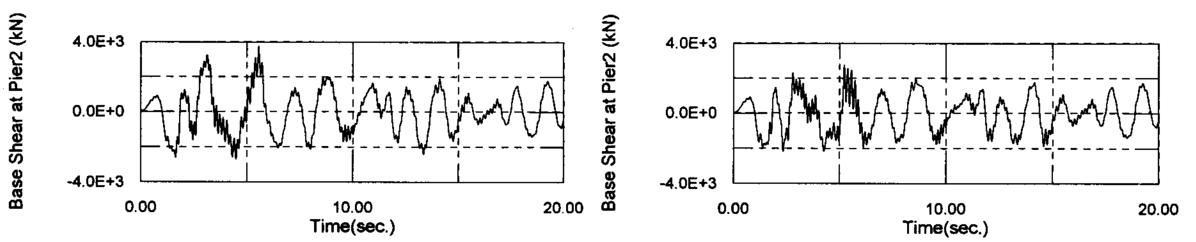


(a) Bridge with LRB's (b) Bridge with PNuD's

Figure 6 Hysteresis Curves for Base Isolators on Pier 1



(a) Bridge with ordinary bearings (b) Bridge with STU's



(c) Bridge with LRB's (d) Bridge with PNuD's

Figure 7 Base Shear on Pier 2

Concluding Remarks

A preliminary study using four computer systems located about 250km apart indicates that on-line parallel experiments through Internet are very feasible, and that the required time for data communication is fairly equivalent to the time required for physical pseudo-dynamic testing on structural components. From this study, it has been experienced that it is not a straight forward task to get through the protection systems of the computer network systems at different institutions. It is relatively easier to get into the systems at academic institutions than those in industries. This parallel testing method using Internet can become more powerful, as the data communication technique using Internet improves.

Table 3 Maximum Responses of Bridges with Different Bridge Bearings

Bearing Conditions on Piers	Ordinary Bearings (Fixed/Free)	STU's	LRB's	PNuD's
Total Acceleration of Deck [g]	0.117	0.211	0.051	0.032
Base Shear on Pier 1 [kN]	1,374	7,731	3,058	2,301
Base Shear on Pier 2 [kN]	11,010	6,309	3,746	2,742
Base Shear on Pier 3 [kN]	1,935	5,360	3,442	2,281
Base Shear on Pier 4 [kN]	1,374	7,731	3,058	2,301
Bearing Deformation 1 [mm]	21.5	-	55.6	60
Bearing Deformation 2 [mm]	-	-	55.8	61.5
Bearing Deformation 3 [mm]	21.7	-	54.4	60.3
Bearing Deformation 4 [mm]	21.5	-	55.6	60
Bearing Reaction 1 [kN]	1.9	7,454	3,211	1,581
Bearing Reaction 2 [kN]	10,840	5,949	3,217	1,583
Bearing Reaction 3 [kN]	1.9	4,924	3,165	1,581
Bearing Reaction 4 [kN]	1.9	7,454	3,211	1,581
Natural Period [sec]	0.98	0.47	2.01	2.01

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References

W-J. Chung, C-B. Yun, N-S. Kim and J-W. Seo, "Shaking table and test pseudodynamic tests for the evaluation of the seismic performance of base-isolated structures", Engineering structure, 21 (4), 365-379, 1998

P.B. Shing and S.A. Machin, "Pseudo-daynamic Test Method for Seismic Performance Evaluation : Theory and Implementation", Report No. UCB/EERC-84101, Univ. of Berkeley, 1984

E. Watanabe, K. Sugiura, K. Nagata, T. Yamaguchi and K. Niwa, "Multi-phase Interaction Testing system by means of the Internet", Proc. of 1st Int'l Conf. on Adv. in Str. Eng. & Mech., Seoul, Korea, 1999