EXPERIMENTAL STUDIES ON SEISMIC BEHAVIOR OF BRIDGE PIER AND PRECAST PILE FOUNDATION

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Abstract

Using an Internet network platform, the seismic response of bridge pier and precast concrete pile foundation is investigated in this study. The network platform, NetSLab, was developed based on client/server concept along with a data model and communication protocols. The platform is capable of transferring control and feedback data and signals among remotely located structural testing laboratories or computers connected by Internet. In these tests, the bridge pier column was simulated numerically whereas the full-scale prestressed/precast pile model was tested physically. The experimental results indicated that the sudden spalling of the thick concrete cover of the precast pile may cause unstable response under earthquake loading, particularly when subjected to the near fault ground motions.

Introduction

A program written in Visual Basic was developed to conduct online pseudodynamic test. It was built based on NETwork Structural Laboratories (NetSLab) (Xiao et al. 2004, 2005; Guo et al. 2006). NetSLab is a preprogrammed application using UniPipe, which is a general interface engine.

The system includes three programs with different functions: controller, virtual tester, and physical tester. In a test, there will be only one controller, but could have multiple virtual testers and physical testers. The current version of program was designed to test a 2DOF system, in which the two substructures could be either numerical model or actual test. The program algorithm is shown in Figure 1. The explicit Newmark method was used in the program as the direct step-by-step integration technique. This method is simple to implement and the stability condition is easy to satisfy (Thewalt and Mahin, 1987).

The physical tester is used to carry out pseudo-dynamic test through Compumotor 6270 motion control for Parker actuators. The virtual tester implements Takeda model (Takeda, 1979) to calculate a softened stiffness of the column model during a test. In the testing system, the

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control box controls motions of actuators and also collects responses, which included displacement and force. As shown in Figure 1, during a test, the controller first reads an earthquake record. Based on the input information about testing structure, the controller can calculate the displacement step for the testing element and the analytical element. The controller then sends the displacement command to the tester for operating the actuator, and to the virtual tester, if it is involved. After the actuator achieves the command position, the testers then send the feedback data to the controller, and the controller then decides the command for next step of the testing. Figure 2 shows selected interfaces of NetSLab applications.

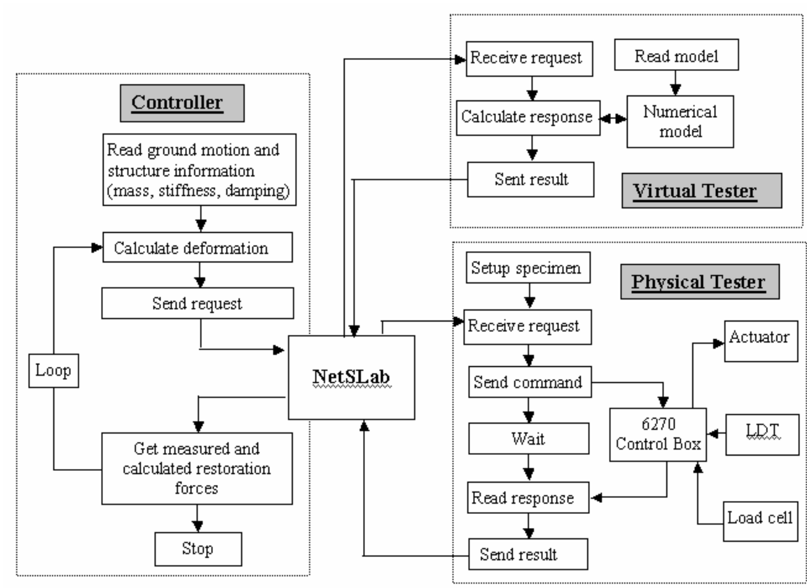
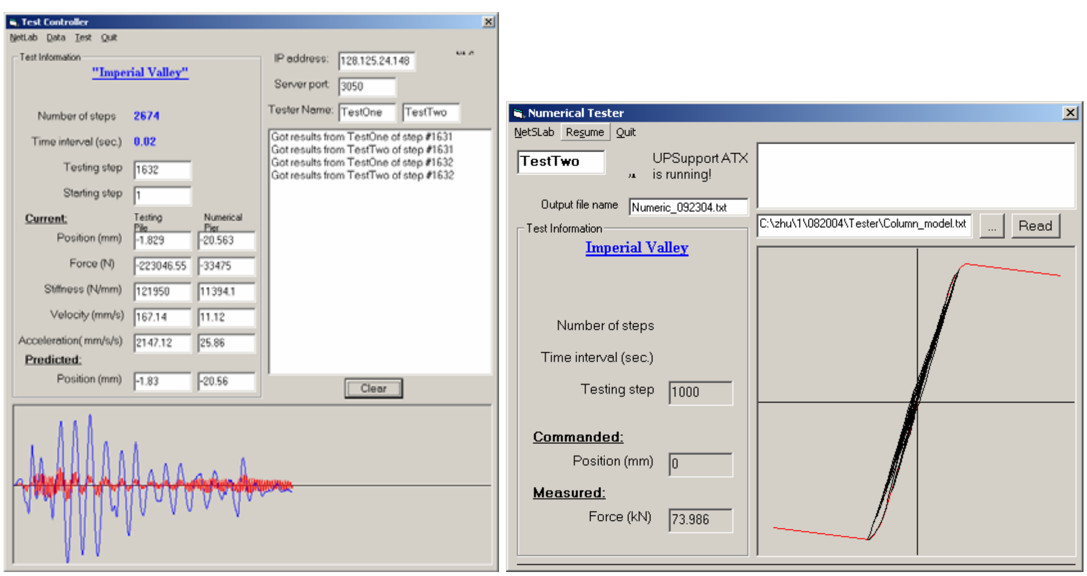


Figure 1. Pseudodynamic test controlling algorithm.



(a) Controller (b) Numerical tester

Figure 2. Program interface.

Experimental Program

Two groups of experimental testing were conducted on a total number of eleven full-scale prestressed concrete piles. In the first group, six piles were tested under quasi-static lateral load, which was either cyclic or monotonic. Four pile specimens were subjected to cyclic lateral load along with a constant axial compressive load. In the second group, five piles were tested pseudo-dynamically with lateral and axial load, which were intended to examine the performance of a bridge bent system under earthquake excitations.

Pile Specimens

The 356 mm square pile segments with a length of 3.66 m were manufactured by a local company. The piles represented the Caltrans metric Class 900 full-scale piles. The design compression capacity of the piles was 900 kN. Figure 3 shows the details of the piles. The piles have a relatively thick cover concrete of 57 mm. The piles were prestressed using six 12.5 mm grade 270 seven-wire low-relaxation prestressing strands. The pre-tensioning force in each strand was 138 kN, with prestress equivalent to $0.75f_{pu}$. The pile segments were designed to simulate the details of the portion near pile-cap, so the longitudinal reinforcement also includes five #25 steel bars. The lateral confining steel used either W11 spiral or W6.5 spiral, both at a spacing of 50mm, providing ρ_s =2.42% and 1.88%, respectively.

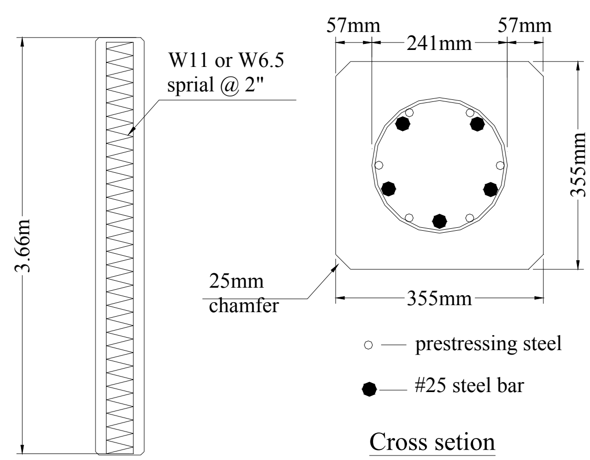


Figure 3. Prestressed/precast concrete pile.

Cyclic Load Testing

Six piles were tested under cyclic lateral load in order to find its moment capacity and ductility performance. The testing parameters include loading pattern, confining steel and axial load level. Figure 4 shows the testing setup, in which a pile was simple-supported at its two ends and a lateral load was applied at the middle span. Two threaded rods were used to apply axial compression force on the piles, which was 890kN for three piles and 0 for the other three. The piles were loaded cyclically with an increased deformation until its drift ratio reach 6%.

All the piles showed satisfactory ductile performance, but the presence of axial load was found to have significant effects on the piles' behavior. The most notable effect is that it caused cover concrete to crush in a brittle manner and thus induced a large lateral strength reduction. Figure 5 shows the hysteretic loops of two piles, one with axial load and the other without. For the pile that tested with axial load, the strength drop was about 30% - 40% of its peak strength, while for the two piles tested without axial load, the strength reduction is gradually, since the crush of cover concrete is a gradual process.

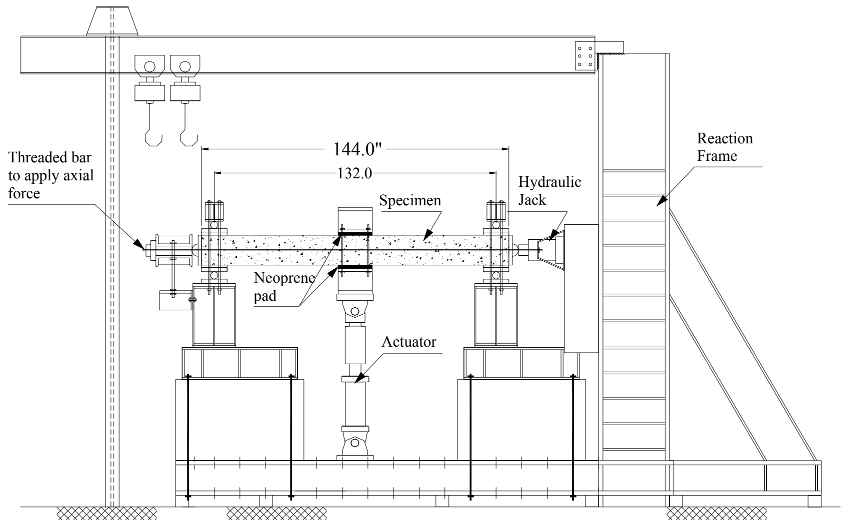
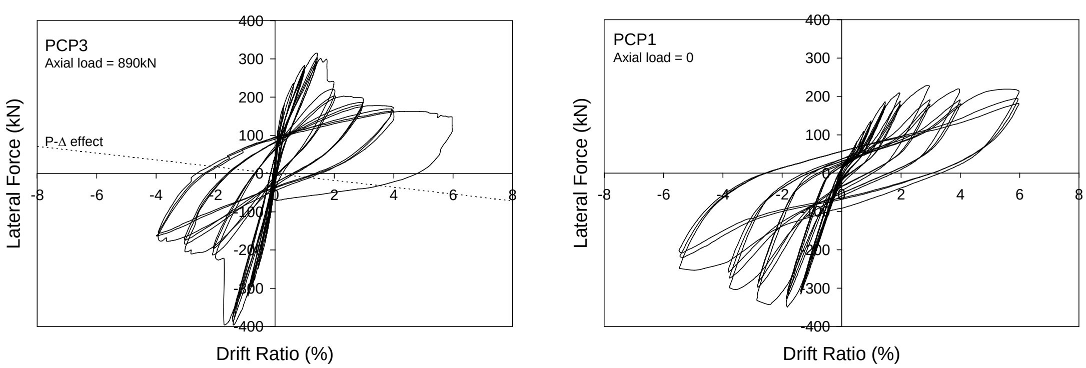


Figure 4. Experimental Test Setup.



(a) (b)

Figure 5. Typical cyclic load testing results for pile: (a) with axial load, (b) without axial load.

<u>Pseudo Dynamic Test</u>

Since the results of the previous mentioned pile tests have shown a large lateral strength drop for piles under combined axial and lateral loads, it is of particular interest to see how it will affect the system response. To answer the question, a series of pseudodynamic tests were conducted to investigate the system response of a bridge bent under lateral earthquake excitations.

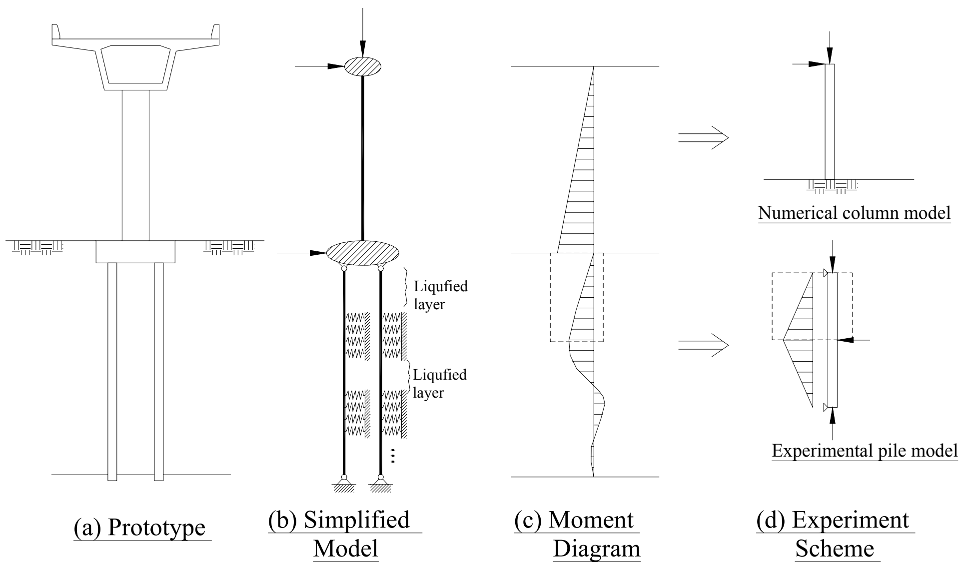


Figure 6. Bridge bent model of pseudodynamic test.

The bridge bent model is shown in Figure 6. The bent is composed of a single column fixed on top of a pile-cap footing and a group of prestressed concrete piles. It was modeled as a 2DOF system with condensed masses, one position at the center of gravity of the super structure on top of the column and the other at the center of the pile cap. The pile–to- pile cap connection was assumed as a pin connection. The test scheme is shown in Figure 6 (d), where a numerical column model and an experimental pile model were used. The pile test setup was the same as that used for cyclic tests. The rocking effect of the foundation was ignored, so the measured pile resistance force was simply multiplied by the number of piles to obtain the total resistance force of the pile group.

Five piles were tested in this pseudodynamic testing program, as shown in Table 1. Two types of piles were used, which are the same as those used in cyclic tests. PsD1 and PsD2 used piles with W6.5 spirals and the other three tests used piles with W11 spirals. For tests with axial load, 36 piles were used in the bent model, while 30 piles were used for the tests without axial load. The reason for doing so was based on the fact that, with axial load, the lateral moment capacity of pile is higher than that without axial load. The different number of piles made the total lateral capacities of the two cases roughly equal. Therefore, the main difference between the test with axial load and the test without axial load would be the different hysteretic responses in the pile. This facilitates the investigation on the effects of sudden degradation in pile load carrying capacities on the seismic behavior of bridge bent.

The earthquake ground motions used in these tests were derived to have the probability of exceedance of 2% in 50 years for NEHRP site category S_D in Los Angeles. Figure 7 shows the two horizontal ground acceleration records were used in the tests. The first one was developed by SAC project, using Northridge earthquake (1994), with a scale factor of 1.29. The second one was from El Centro earthquake (1940), with scale factor of 3.032.

Table 1. Pseudodynamic Testing Matrix.

Specimen	Reinforcement Details	Axial Load	Number of Piles	Earthquake Ground Acceleration Record
PsD 1	Six 12.5mm grade 270 strand Five #25 steel bar W6.5 spiral wire @50mm	890 kN	30	Northridge, 1994
PsD 2		0	36	
PsD 3	Six 12.5mm grade 270 strand Five #25 steel bar W11 spiral wire @50mm	890 kN	30	
PsD 4		0	36	
PsD 5		890 kN	30	El Centro, 1940

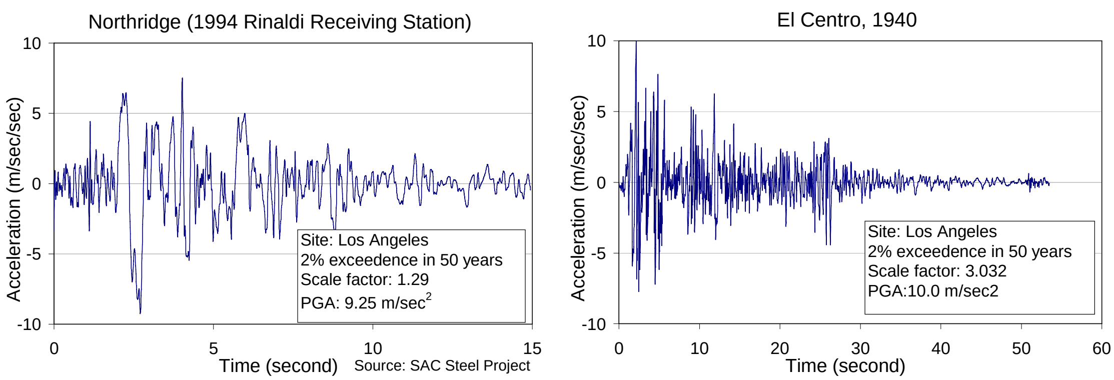


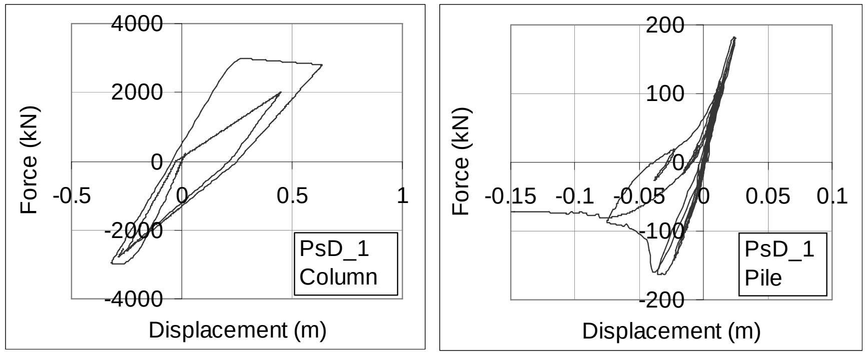
Figure 7. Earthquake ground acceleration records.

Discussion of Results

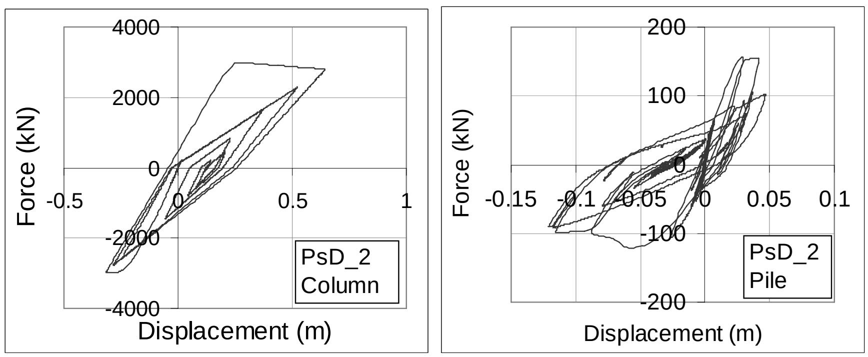
The hysteretic loops and response time histories of the first four pseudodynamic tests are shown in Figure 8 and 9. Test results confirmed that when a pile experiences a sudden drop due to the spalling of the thick concrete cover, the bridge system response may become unstable with a significant residual pile displacement.

The two tests with axial load, PsD1 and PsD3, were stopped because the actuator reached its limit. For the two tests without axial load, the piles were able to sustain the whole earthquake record. Although for PsD1 and PsD3, the system may not reach the collapse state yet, it is clear that after cover concrete crushed, the capacity of the pile foundation dropped, in much larger pile deformation than the other two cases.

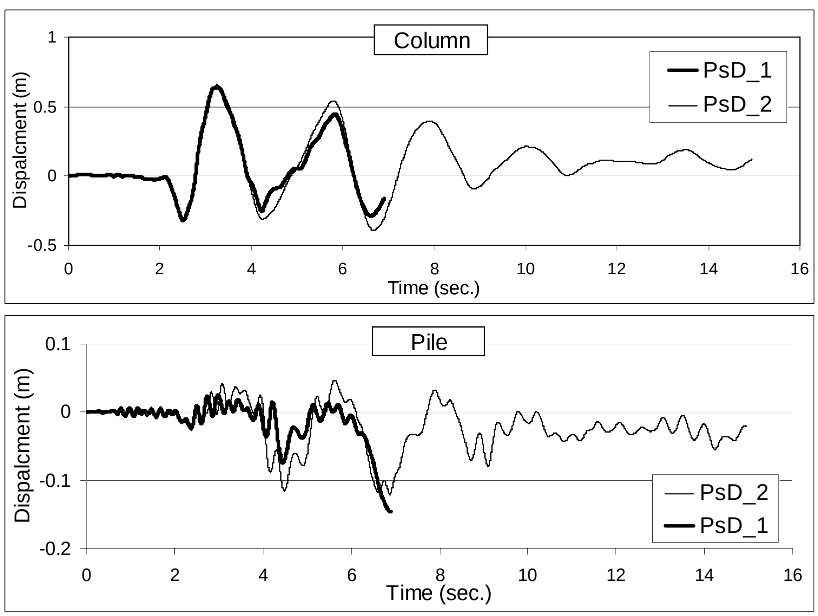
The difference on the pile foundations has little effect on the response of the columns, which was caused by two reasons: 1) The response of the column was much larger than that of the piles; 2) Pinned connection was used for the pile - pile cap connection and rocking effect of the pile cap was ignored, so no rotation at the bottom of the column was considered.



(a) Hysteretic loops for PsD1

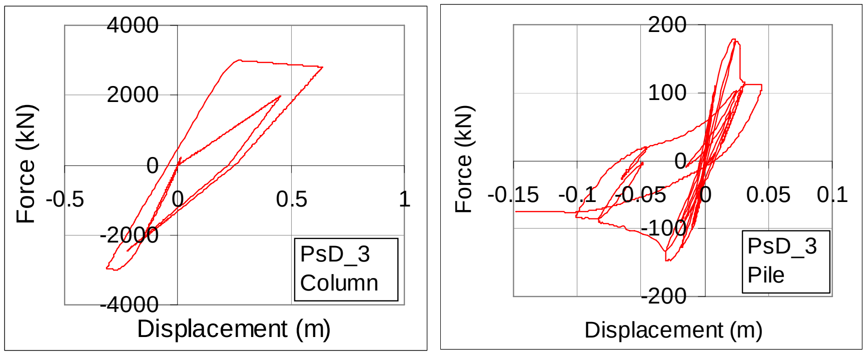


(b) Hysteretic loops for PsD2

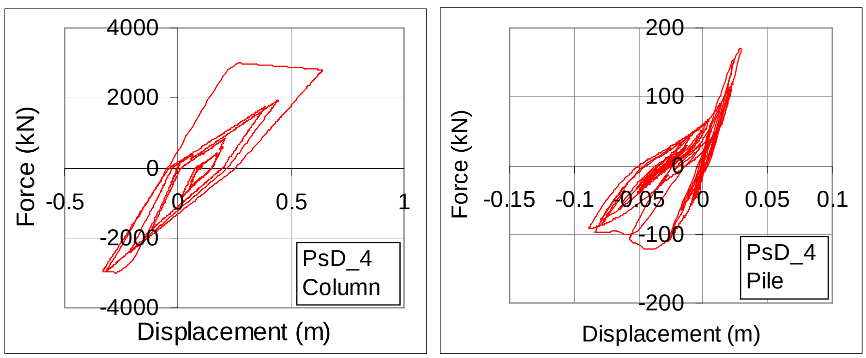


(c) Comparison of time history for PsD1 and PsD2

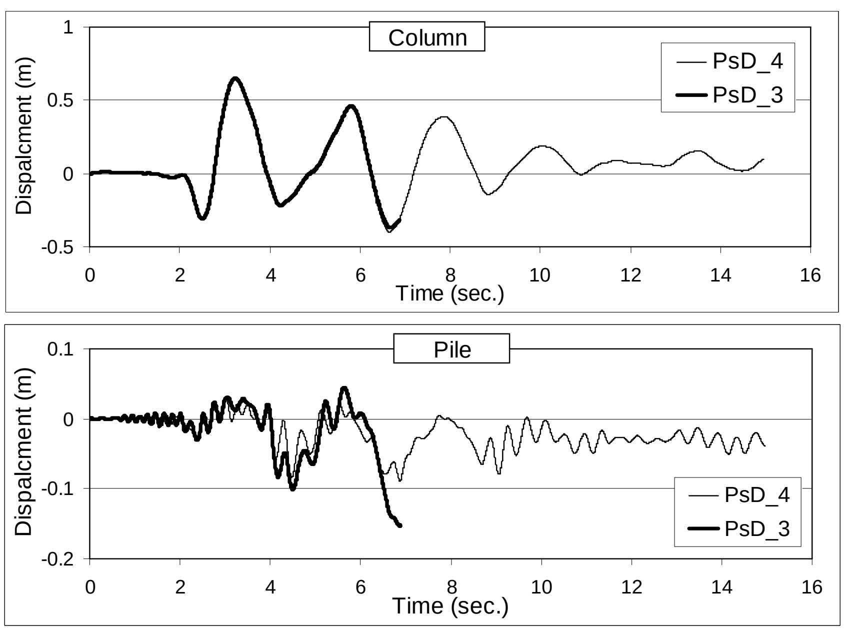
Figure 8. Test results for PsD1 and PsD2.



(a) Hysteretic loops for PsD3



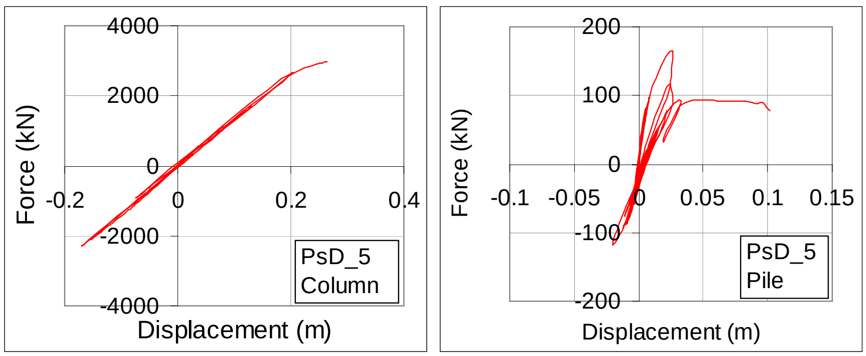
(b) Hysteretic loops for PsD4



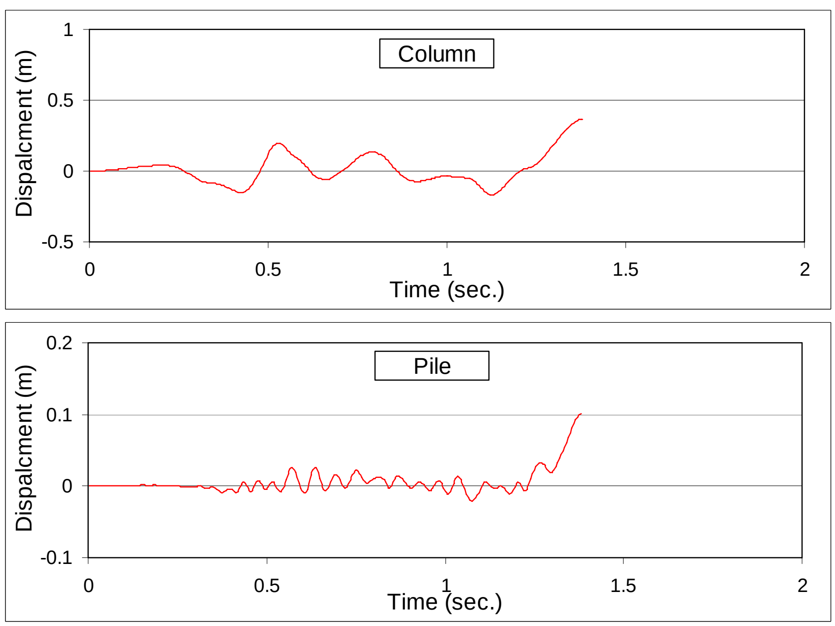
(c) Comparison of time history for PsD3 and PsD4

Figure 9. Test results for PsD3 and PsD4.

Figure 10 shows the results of test PsD5, which used scaled El Centro earthquake record. The system only sustained less than two seconds of earthquake motion since the pile's displacement reached the limit of the actuator. But at that time, the response of the column was quite small and still in its elastic range, unlike the responses from the previous tests. This test provided an example that a bridge pier may go through an earthquake with only small cracks, while its foundation could already have sever damages.



(a) Hysteretic loops for PsD5



(b) Response time history for PsD5

Figure 10. Test results for PsD5.

<u>Conclusions</u>

Pseudo dynamic tests were conducted on the seismic response of bridge pier and pile foundation. The communication and data transferring during the tests was achieved using an Internet based network platform, NetSLab. The platform was proved to be easy to use and reliable. Based on the results of the pseudo dynamic tests of the single column bent bridge pier with prestressed/precast concrete piles, the following conclusions are drawn:

1. The crushing of the thick cover concrete of a precast concrete pile causes a sudden degradation in its lateral load carrying capacity.
2. Although the well-confined pile core behave stably under imposed cyclic loading after the concrete cover spalling, the system behavior may be unstable with excessive residual displacement due to the sudden degradation of the pile capacity.
3. During an earthquake, the pile foundation of a bridge could suffer damage even though its pier shows little sign of damage.

Acknowledgments

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