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COLLABORATIVE PSEUDO DYNAMIC TEST ON BUILDINGS WITH NEW COLUMN BASES USING DISTRIBUTED LOADING SYSTEM

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ABSTRACT :

One of authors has proposed a scheme for Internet-based collaborative structural analysis (CSA) in which many researchers worldwide can collaborate and unify their different programs and structural models. The distributed loading system enables us to simulate the variation of rotational stiffness and bending moment carrying capacity of column bases and can be operated remotely through the Internet. Hence, the technique of Internet-based structural analysis is used to perform a collaborative pseudo dynamic test on a building frame with an exposed column base. We have also proposed a non-slip-type exposed column base with wedge devices, which shows non-slip-type restoring force characteristics. Slip does not take place and the load in the loading cycles builds up from the origin. To verify the performance of the distributed loading system and newly proposed column-bases, pseudo dynamic tests were performed on a 5-story 2-bay steel frame building with the proposed column bases. The structure was split into analytical substructures and experimental substructures. The experimental substructures were the exterior column's base or the interior column's base, and the other columns, beams, slab, column bases and external forces are simulated as analytical substructures.
The test series was an elasto-plastic pseudo-dynamic test in which the maximum ground velocity of the earthquake motion was set to 50kine and the experimental substructure was a column base of an interior column. The column bases were conventional column bases and non-slip-type column bases. The excitation was given twice continuously. From these test results, the following conclusions are drawn.
1) The maximum base plate rotation response of the non-slip-type column base was less than 10% of that of the conventional column base under severe earthquake.
2) For a conventional column base, the maximum story drift of the second excitation was 15% larger than that of the first excitation. However, for a non-slip-type column base, almost all responses were the same except for the initial elastic responses.
3) Hence, a non-slip-type column base has high self-rehabilitation and its structural characteristics remain unchanged after a severe earthquake. Furthermore, it is maintenance free because its structural characteristics were unchanged after two severe earthquakes.

KEYWORDS: collaborative structural analysis, numerical analysis, local buckling, full-scale steel building, collapse

1. INTRODUCTION

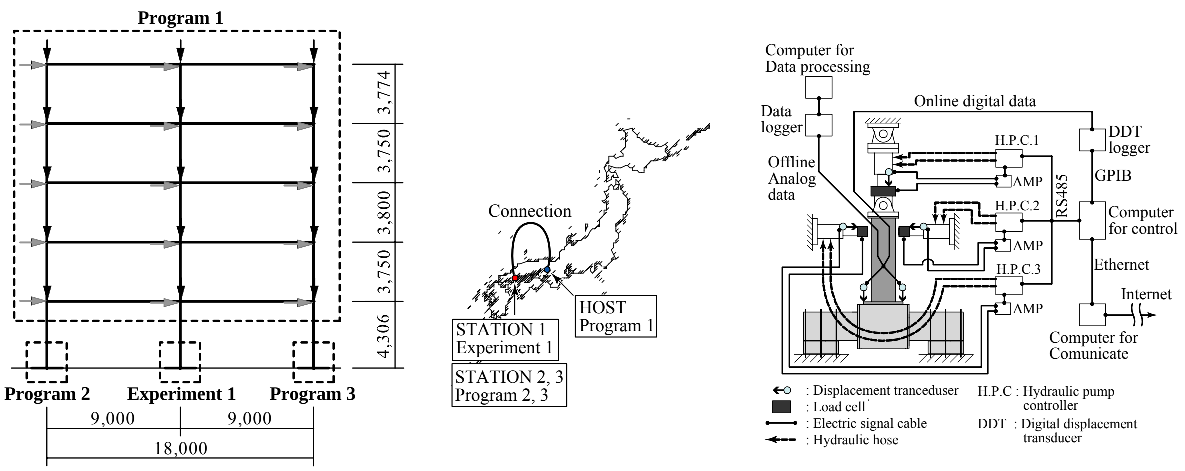
Generally, an exposed-type column base consists of anchor bolts and an elastic thick base plate. Its restoring force characteristics are observed to be slip-type due to a gap opening up between a nut of the anchor bolt and the base plate, caused by plastic elongation of the anchor bolt. Many studies have shown that slip-type behavior has almost no effect on the response characteristics of upper stories of moment-resisting frames. However, column bases need to have higher energy absorption capacity when the strength of the first story is lower than those of the other stories due to energy concentration in the first story. The first story requires a large story drift angle to absorb the large energy in exposed-type column bases that have slip-type characteristics. A new technique for improving slip-type behavior has been proposed by the authors [Takamatsu, Tamai and Yamanishi

2005]. Slip behavior can be decreased by driving a wedge under constant compression with a spring into the gap between the nut and the base plate, thus eliminating the gap generated by the expanded anchor bolt. This exposed-type column base with wedge devices thus shows non-slip-type restoring force characteristics. Slip does not take place and the load in the loading cycles builds up from the origin.
Tada and Kuwahara proposed a scheme for Internet-Based structural analysis in which many researchers worldwide can collaborate and unify their different programs and structural models [Tada and Kuwahara 2004]. We made a loading system on a column base that enables us to simulate the variation of rotational stiffness and bending moment carrying capacity under varying axial forces [Tada, Tamai and Yoshimura 2005]. Hence, the technique of Internet-based structural analysis is used to perform a collaborative pseudo-dynamic test on a building frame with a non-slip-type column base subjected to severe earthquake loads.
In this study, a collaborative seismic performance evaluation technique has been applied to 5-story 2-bay steel buildings with non-slip-type column bases under severe earthquake ground motions.

2. OUTLINE OF DISTRIBUTED LOADING SYSTEM

2.1 SYSTEM COMPONENTS

Let us consider a collaborative pseudo-dynamic test that uses the distributed loading system. The project target is a 5-story 2-bay building frame, as shown in Figure.1(a).
We divided the building into 4 sub-structures comprising three cantilevers with column-bases and a 5-story frame. Program 1, Program 2, 3 and Experiment 1 exist separately, as shown in Figure 1(b). Program 1 can analyze the column, beam and panel in detail. Program 2, 3 can analyze the column with column base in detail. Experiment 1, shown in Figure 1(c), can evaluate the complicated restoring force of the column base after failure.
The resisting bending moment of the column base is influenced by vertical load transmitted through the upper story. The first- and second-story drift varied with the rigidity of the column base. Hence, to determine the building's strength, it is necessary to unify these Programs and the Experiment, and to exchange information between them. CSPE is a method for connecting the station and host through the Internet.



(a) Target structure (b) Location of organization (c) Experimental facility

Figure 1 Concept of collaborative a seismic performance evaluation with distributed loading system

2.2 DATA EXCHANGE PROCEDURE

Each program and loading system shares horizontal displacement and rotation as a boundary degree of freedom. We adopt a procedure that uses a direct socket connection over TCP/IP and a Proxy server as a countermeasure to Firewall blocking. A Firewall refuses a data connection from outside a research organization and bypasses the data connection from inside it. The proxy server acts such that it is always waiting for a connection demand, and joins two clients in communication. If we use a proxy server located outside the organization, we can overcome the protection of Firewall within it. This procedure was proposed and coded by Dr. Peng Pan of Kyoto Univ. It enables high-speed communication regardless of the presence of Firewall.

2.3 TEST APPARATUS

We outline the loading system for the full-size steel column base hereafter. The loading frame is shown in Figure.2. Its outer dimensions are 9,000mm x 6,000mm, and it consists of members, BH-1000x450x26x20 and BH-800x450x26x40 of SM490 steel. It is equipped with three oil jacks, whose loading capacity and maximum stroke are 3000kN and 500mm, respectively. The full-size inverted T-shaped column specimen is fastened with a high-strength bar. Vertical and horizontal loads are imposed on the specimen by the three oil jacks, which are controlled simultaneously by checking the values of load, displacement and stroke.
The control system setup is shown in Figure 1(c). Each Jack is equipped with a load cell and a digital displacement transducer (load and displacement sensor). The sensors are connected with the oil pressure control unit. The oil pump, solenoid valve and high-speed release valve control the load, stroke and displacement at 10ms time intervals. Three independent hydraulic power unit controllers are connected to a process computer via an RS485 telecommunication line. As the process computer is connected to the Internet via an Ethernet line, we can carry out a distributed experiment with investigators and research organizations around the world through a socket communication program. Detailed data of a test specimen are recorded with other measurement systems.

Table 1 Section of column and beam

Layer	G1	Floor	C1
R	H - 400 x 300 x 11 x 18	5	□ - 450 x 450 x 19
5	H - 488 x 300 x 11 x 18	4	□ - 500 x 500 x 19
4	H - 488 x 300 x 11 x 18	3	□ - 500 x 500 x 19
3	H - 588 x 300 x 12 x 20	2	□ - 550 x 550 x 22
2	H - 588 x 300 x 12 x 20	1	□ - 550 x 550 x 22

SN400 (σ_y = 235 N/mm^2)
BCR295 (σ_y = 295 N/mm^2)

Effect from concrete slub to beam : 1.4・Es
Es : 205 (kN/mm^2)

Table 2 Design load

	Dead load (N/m^2) Roof	General floor
Slab	3,530	3,530
Waterproofing lay	1,470	
Interior material	200	200
Beam	390	390
Column	100	100
Structural wall	490	490
Total	6,180	4,710

	Live load (N/m^2) Roof	General floor
Frame	650	1,800
Seismic load	300	800

Dead load by parapet of external wall (N/m^2)
2,940

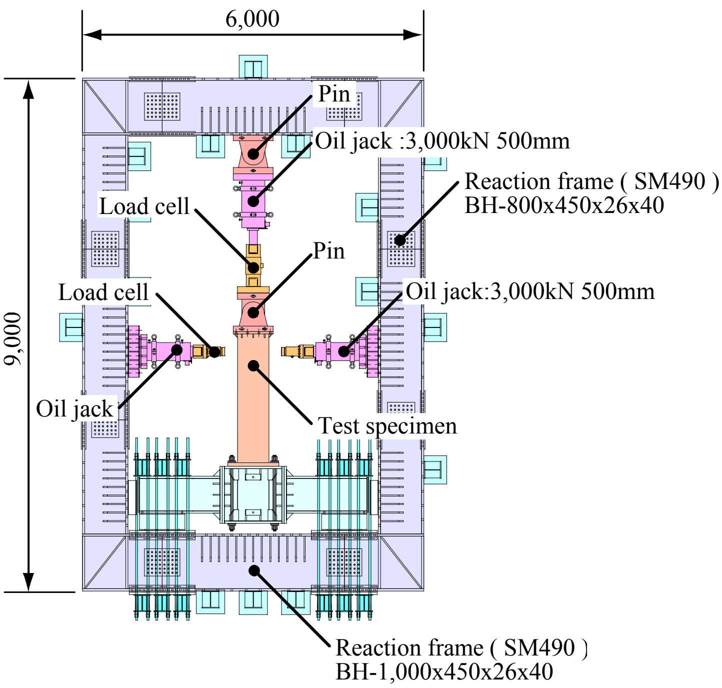
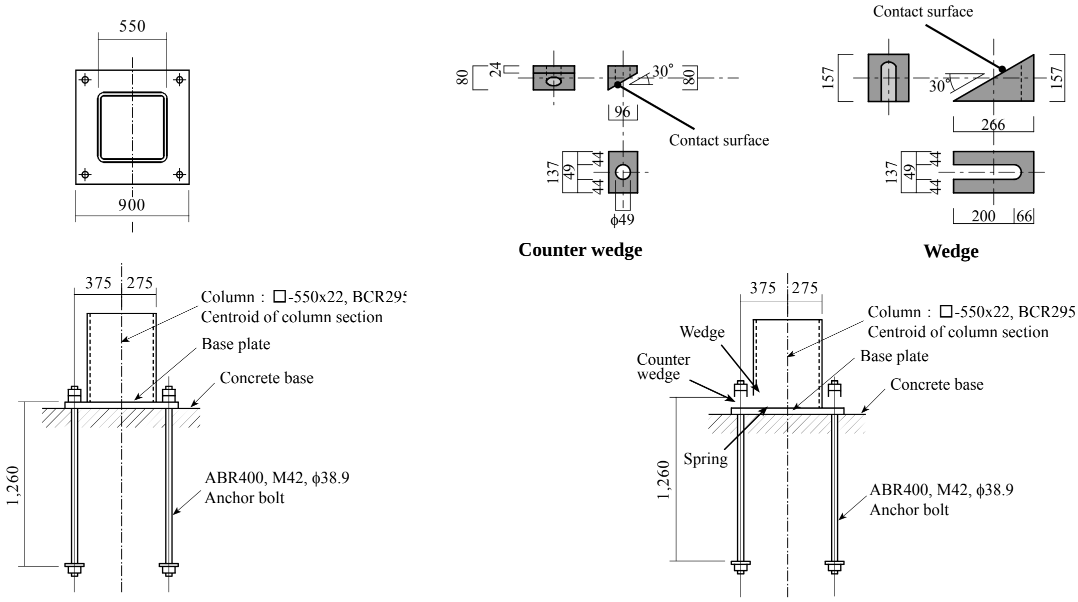


Figure 2 Loading system of column-base in STATION 1



(a) Conventional column-base (b) Non-slip-type column-base

Figure 3 Conventional and presented column-base

3. COLLABORATIVE PSEUDO DYNAMIC TEST ON 5-STORY BUILDINGS

3.1 OVERVIEW OF BUILDING

An elevation of the building is shown in Figure 1(a). The sectional properties of the beam and column members are shown in Table 1.
The target is a 5-story 2-bay steel frame with square steel tube columns and a narrow H-shaped beam.
The steel grades are SN400 (σy=235N/mm2) for the beam and BCR295 (σy =295N/mm2) for the columns. The beam is assumed to be 1.4 times as stiff as its original flexural rigidity because it incorporates a 150mm-thick concrete slab.
The dimensions of the exposed column base are shown in Figure 3. Table 2 shows the design loads.
The frame stress under vertical load was within the permissible range and the story drift angle at each floor was within the 1/200rad range under horizontal and vertical loading required by Japanese standard law, and the configuration of the collapse mechanism was the so-called "Strong column-Weak beam" mechanism. The maximum base shear factor of the frame was 0.47.

3.2 NON-SLIP-TYPE EXPOSED COLUMN BASE

Generally, an exposed-type column base consists of anchor bolts and a thick elastic base plate. The restoring force characteristics of the column base are observed to be slip-type due to a gap formed between a nut of the anchor bolt and the base plate, caused by plastic elongation of the anchor bolt.
A new technique for eliminating slip-type behavior has been proposed by the authors. The non-slip-type exposed column base that we proposed is presented in Figure 3(b). The slip behavior can be decreased by driving a wedge under a constant compression with a spring into the gap between the nut and the base plate, thus eliminating the gap generated by the expanded anchor bolt. This exposed-type column base with wedge devices shows non-slip-type restoring force characteristics. Slip does not take place and the load in the loading cycles builds up from the origin.

3.3 OUTLINE OF TESTS

The structure is split into analytical substructures and experimental substructures. The experimental substructures are the interior column's base, and the other columns, beams, slab, column bases and external forces are simulated as analytical substructures. The excitation is the NS component of EL CENTRO 1940 normalized by 15 and 50kine by maximum ground velocity, duration 10s, and first and second natural period of the vibration system 0.817s and 0.269s, respectively. The time step of the experiments was 0.005s, and the damping factor was set to 0.02 for the main structural steel frame.

3.4 TEST SPECIMEN

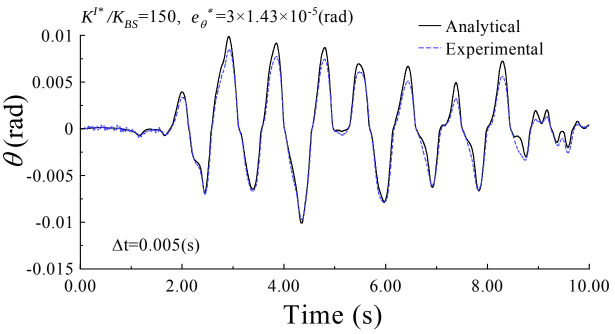
Figure 3 shows the test specimens. A hollow square-section column (550x22, BCR295) was welded to a base plate (PL-900x900x60, SM490). The column was fastened to the steel base by four rolled threaded anchor bolts (M42, ARB400). The length of the anchor bolts between nuts was 1,260mm.

4. TEST RESULTS AND DISCUSSIONS

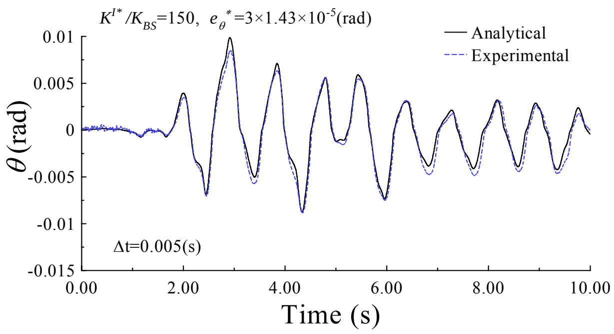
The test results are shown in Figures 4 and 5. Figure 4(a), (b) show the time-history of predictor base plate rotation θ. They show the results for an ordinary column base and a non-slip-type column base of an interior column, respectively. Figures 5(a), (b) and Figures 5(c), (d) show results for an ordinary column base and a non-slip-type column base of an interior column, respectively. Figures 5(a), (c) show the bending moment M vs. θ relation, Figures 5(c), (d) show the base shear force normalized by the total weight of the building Bi vs. first story drift angle ri relation. The analytical results from the finite element method are also shown in Figures 4~5.

From these results, the following conclusions are drawn.
The experimental time history of base plate rotation in Figure 4 is in good agreement with the analytical one.
The pseudo-dynamic test method using the presented distributed loading system can simulate the elastic response of a 5-story steel building under a strong earthquake. ??From the bending moment at column-base vs. base plate rotation relation in Figure 5,the shape of the hysteresis loop in the M vs. θ relation is a "double flag” shape.
Slip phenomena in the M vs. θ relation are observed for the conventional column base, but not for the non-slip-type column base. The maximum base plate rotation response of the non-slip-type column base was less than 10% of that of the conventional column base under severe earthquake. Variations of vertical force on the column base are very large in an exterior column. The resisting bending moment amplitude of the column base was varied by 20% in the positive and negative directions due to the effect of variation of vertical force.

Finite element analysis, presented in reference [Tamai 2003], can simulate the difficult restoring force characteristics. Base shear coefficient vs. 1st story drift angle showed Character "S"-shaped restoring force.
For a conventional column base, the maximum story drift of the second excitation was 15% larger than that of the first excitation. However, for a non-slip-type column base, almost all responses, M vs. θ and Bi vs. ri relations, were the same except for the initial elastic responses.
Hence, a non-slip-type column base has high self-rehabilitation and its structural characteristics remain unchanged after a severe earthquake. Furthermore, it is maintenance free because its structural characteristics were unchanged after two severe earthquakes.

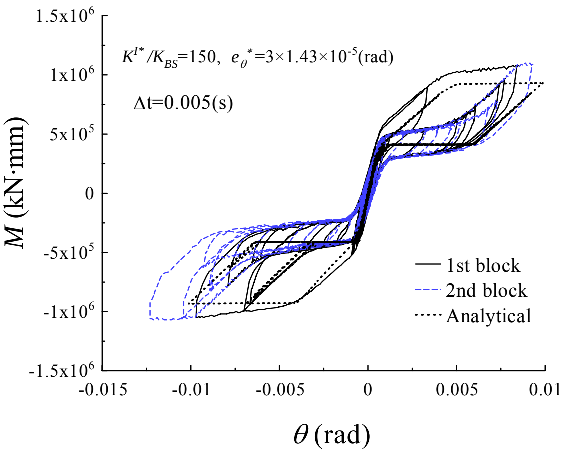


(a) Conventional column-base

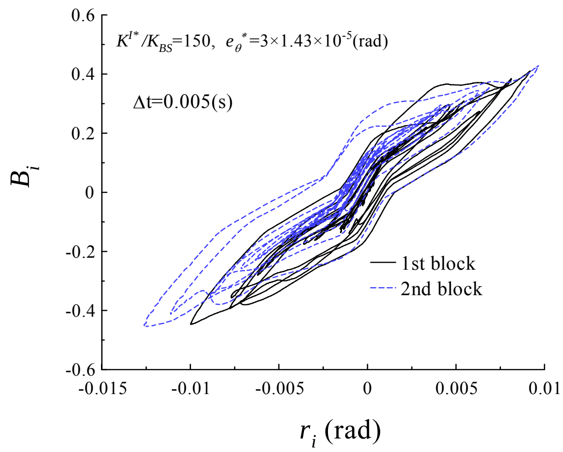


(b) Non-slip-type column-base

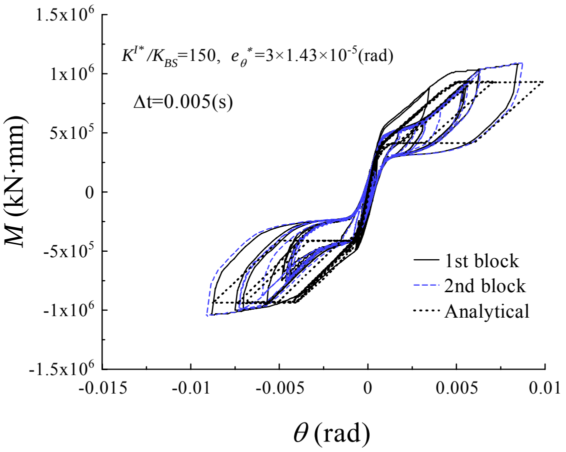
Figure 4 Time-history of base plate rotation



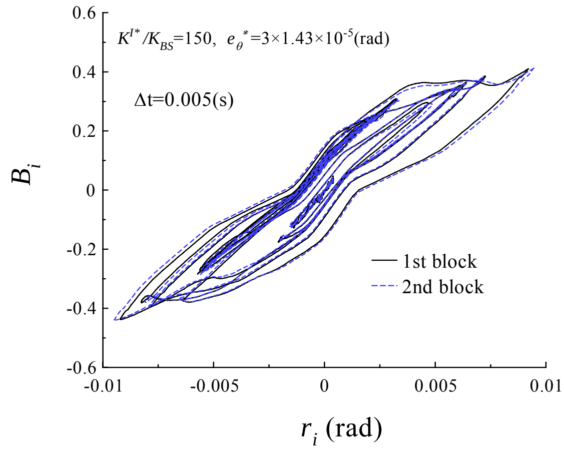
(a) Bending moment at column-base vs. base plate rotation relation Conventional column base (interior column)



(b) Base shear vs. story drift angle relation Conventional column base (interior column)



(c) Bending moment at column base vs. base plate rotation relation Non-slip-type column base (interior column)



(d) Base shear vs. story drift angle relation Non-slip-type column base (interior column)

Figure 5 Results of dynamic response

5. CONCLUSIONS AND REMARKS

Collaborative seismic performance evaluations using distributed loading system were carried out on 5-story 2-bay steel buildings, and the effectiveness and applicability of a distributed loading system was investigated. The results obtained from these tests are summarized as follows:

1) The approach of using a socket connection and a Proxy server enables us to communicate with the whole world with the loading system through the Internet.
2) The distributed loading system for a full-scale column base can apply a load up to maximum strength.
3) A pseudo-dynamic test method using the presented distributed loading system can simulate the seismic response of a 5-story steel building under a strong earthquake.
4) The maximum base plate rotation response of the non-slip-type column base was less than 10% of that of the conventional column-base under severe earthquake.
5) A non-slip-type column base has high self-rehabilitation and its structural characteristics may not change after a severe earthquake.
6) The loading system can be used easily for seismic performance evaluation to develop a new structural system.

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