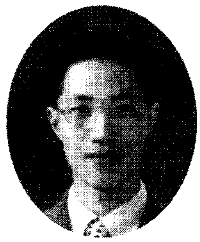
Seismic Behavior of Precast Frames with Hybrid Beam-Column Connections

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ABSTRACT

A precast frame system with hybrid beam-column connections was proposed in this study. An analytical study evaluated the system under seismic loadings. Four buildings with different heights were modeled in which each building had three types of joint details (A, B, C). Thus, twelve buildings were examined with variables such as building height and joint detail. Four earthquake records were applied to the buildings as input ground motions. All the records were normalized to the intensity of 0.25g to assess behavior under the same intensity of seismic excitation. All the joint types showed almost identical results except for the Mexico earthquake which was scaled up from 0.1g to 0.25g. Buildings with the type C joint exhibited the largest deflection for the Mexico earthquake. It was concluded that type B joint could be used in a high seismic zone and the type C joint could possibly be used in the regions of low to medium seismic activity.

Keywords : precast, debonded, posttensioning, seismic, displacement, energy dissipation

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1. INTRODUCTION

Performance of a building system subjected to seismic forces is influenced by strength, stiffness, ductility. It may be easy to increase strength and stiffness simply by increasing sectional volumes or using higher strength materials. However, careful attention is necessary to obtain a desirable level of ductility. It would be much more critical for a precast concrete system in a high seismic zone. The precast concrete system should have enough deformational capability even if it is not used as the seismic resistant system.

A structure constructed with precast concrete elements should find an economical and practical means of connecting them with adequate stiffness, strength, ductility, and stability. A precast concrete structure, therefore, is usually allowed if it is demonstrated that the proposed system can emulate a comparable monolithic reinforced concrete structure.

In this study, a structural system was proposed from the examination of various precast systems. Then, the seismic behavior of the system was investigated with existing earthquake records. The investigation was conducted in a such way of comparing it with a typical monolithic concrete system.

2. PREVIOUS STUDIES

Recently the National Institute of Standards and Technology (NIST) in USA began to study a precast concrete frame system. Four phases of research program were carried out to develop a system which can show equivalent capability of monolithic concrete system even at high seismic zones. The research program of NIST is summarized in Table 1.

The system is composed with beams and columns which are connected with posttensioning steels. During first two phases, posttensioning tendons were fully grouted along the length of tendons. However, it was found that the entire prestress be lost at zero deformation of a structure if the prestressing steel undergo large inelastic deformation. Fig. 1 shows one of observed results[1,2].

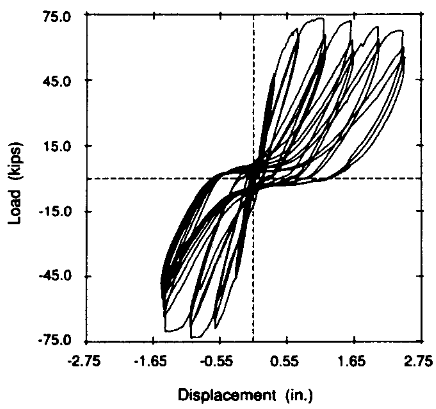

Fig.1 Test results of PC concrete system with bonded tendons

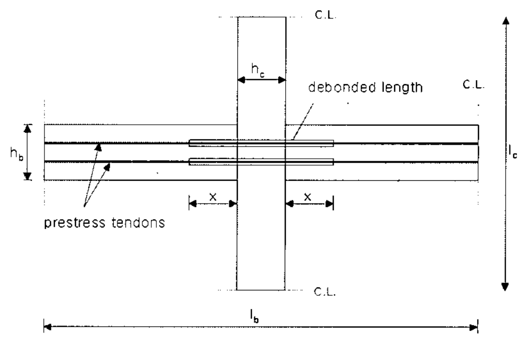

Fig.2 PC concrete system proposed by Priestley and Tao

Table 1 Summary of previous studies

Test Phase		Specimens	Zone	Type*1	PT Steel Type*2	PT Steel Bond*3	f_{se}/f_{su}	Mild Steel	Test Results μ_u	Test Results Δ_f
I		A-M-Z2	2	M	-	-	-	-	6	4.1
		B-M-Z2	2	M	-	-	-	-	6	4.3
		A-M-Z4	4	M	-	-	-	-	6	2.6
		B-M-Z4	4	M	-	-	-	-	6	2.5
		A-P-Z4	4	P	B	F		-	10	3.0
		B-P-Z4	4	P	B	F		-	10	3.4
II		A-P-Z2	2	P	S	F	0.69	-	4	3.1
		B-P-Z2	2	P	S	F	0.66	-	4	3.4
		C-P-Z4	4	P	B	F	-	-	12	4.8
		D-P-Z4	4	P	B	F	-	-	12	4.9
		E-P-Z4	4	P	S	F	0.65	-	12	5.2
		F-P-Z4	4	P	S	F	0.66	-	12	5.0
III		G-P-Z4	4	P	S	P	0.66	-	>14	3.9
		H-P-Z4	4	P	S	P	0.66	-	>14	3.6
IV	A	I-P-Z4	4	P	S	F		F		2.7
		K-P-Z4	4	P	S	F		F		3.6
		J-P-Z4	4	P	B	U		F		3.1
		L-P-Z4A	4	P	S	U		-		1.5
		L-P-Z4B	4	P	B	U		-		1.5
		L-P-Z4C	4	P	S	U		U		2.0
	B	M-P-Z4	4	P	S	P	0.45	P		3.4
		N-P-Z4	4	P	S	P	0.42	P		2.9
		O-P-Z4	4	P	S	P	0.41	P		3.4
		P-P-Z4	4	P	S	P	0.45	P		>3.0

*1 M = monolithic, P = precast,
*2 B = prestressing bars, S = strands
*3 F = fully grouted, P = partially grouted, U = unbonded
*4 μ_u = ultimate displacement ductility
*5 Δ_f = story drift at failure

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Table 2 Characteristics and advantages of precast frame system

	construction	structural behavior	purpose	advantages
posttensioning steel	pratially or fully unbonded	no inelastic deformation	connection by clamping force	restored with little damages
reinforcing bar	partially ungrouted	inelastic deformation	energy dissipator	-
column	single or multistory	rigid body	precast	-
beam	single bay element	rigid body	precast	-
panel zone	same body with column	higher shear strength	precast	less reinforcements
beam-column interface	day joint	shear strength by friction	simple construction	low repairing cost

Then, Priestley and Tao[3] proposed a precast concrete system with partially debonded tendons as shown in Fig. 2. The debonding technique of prestressing steel is proposed to prevent from the zero slope of hystersis loop upon load reversal. Since the tendons are not bonded with surrounding concrete, they do not deform beyond the elastic range. Fig. 3 shows one of test results for the system with debonded tendons[2].

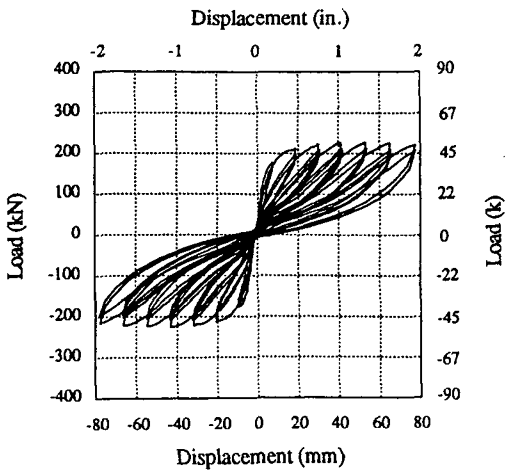


Fig.3 Test results of PC concrete system with debonded tendons

During third and fourth phases of research by NIST[4,6], the system was developed further to provide more ductility than the system of Priestley and Tao. The system is composed with beams and columns which are connected with posttensioning steels and mild steels. The posttensioning steels located at the mid-height of the section are either partially or totally unbonded. The mild steels are placed at the top and bottom of the section to work as the energy dissipators. It is also partially ungrouted near the beam-column joint to prevent from that large deformation is concentrated on the beam-column interface. The characteristics and the advantages of the precast frame system are summarized in table 2.

3. PROPOSED SYSTEM

A precast system with hybrid PC beam-column connections was proposed recently by Samsung and STRESS[8]. The system called HI-Beam system (see Fig. 4) consists of steel beams with reinforced concrete ends and reinforced concrete columns. The joints are connected with wet concrete during the erection stage.

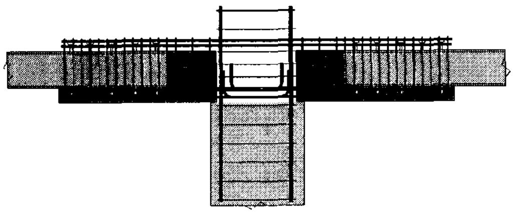


Fig.4 HI-Beam system with wet joint

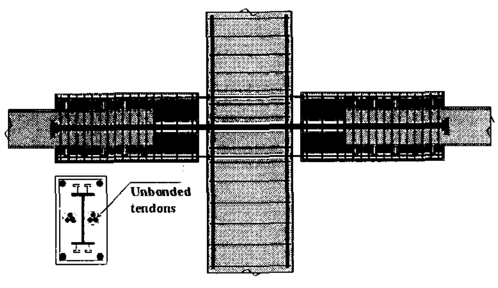


Fig.5 PC concrete system with dry joint

In this study, a structural system was proposed from comparing those two systems while taking advantages of each system. The proposed system (see Fig. 5)

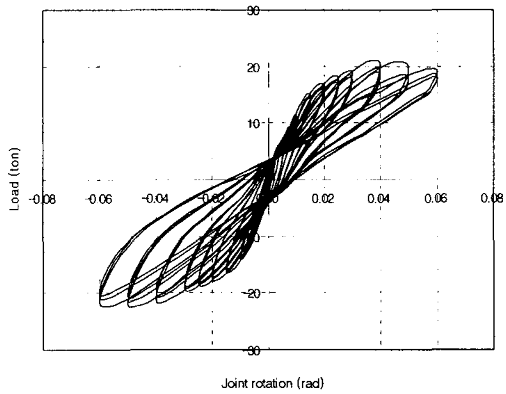
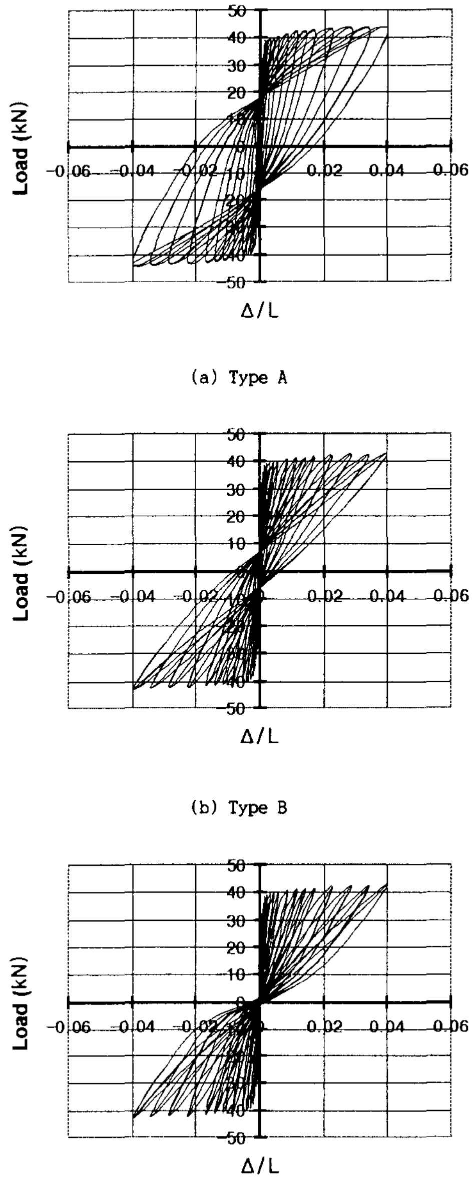


Fig.6 Test results of PC concrete system with debonded tendons and mild steels

also consists of steel beams with reinforced concrete ends and reinforced concrete columns as HI-Beam system. However, the joint is connected by the method developed by NIST or Priestley and Tao. Thus, no wet concrete is required for the system. The advantages of proposed system against those two systems can be following.

(1) simple construction
(2) possibility of long span beam
(3) easy posttensioning process

The first advantage coming from the possibility of dry joint is obtained from HI-Beam system. The others are the advantages against the system developed by NIST or Priestley and Tao. Long span beams are possible because the central region consists of structural steel. No grouting work for tendons is required in the proposed system because the tendons are used within a narrow region. A typical test result with the proposed system is illustrated in Fig. 6[8].



(a) Type A

(b) Type B

(c) Type C

Fig.7 Hysteretic loops

4. ANALYSIS

An uncertainty associated with the proposed system is a possible increase in lateral displacements due to the lack of hysteretic energy dissipation. In order to examine the seismic behavior, three types of hysteretic loops shown in Fig. 7 were derived in this study.

Type A loop represents the behavior of a monolithic reinforced concrete frame with a high level of ductility. Type B has prestressing tendons partially debonded at the mid-height of the section and mild steels at the top and bottom of the section. Type C has only prestressing tendons partially unbonded. Thus, type B would show more ductile behavior than type C.

The hysteretic loops were derived considering experimental results shown in Fig. 3 and 6 which corresponded to type C and type B, respectively. The joint strengths were set to be identical for the purpose of comparison.

The analytical models consist of four buildings of 5, 10, 15, 20 stories. The periods of buildings were ranged between 0.55 second to 1.72 second. All the models have four bays equally spanned with 15m. The story height is 4m and the column size is 98cm x 98cm. The beam section at a connection is 116cm x 66cm. Each building was designed individually with type A, type B, and type C. Then, four different earthquakes were applied to each building. It means that a total of 48 analyses was carried out.

The input motions were selected from four different earthquakes which were shown in Table 3 and Fig. 8. The Mexico city earthquake scaled up to 0.25g was used to investigate the structures under the worst condition because the proposed structure would usually be flexible due to their long span. All the records were normalized to the intensity of 0.25g to assess the behavior of structures under the same intensity of seismic excitation. The dynamic analysis was carried out with IDARC program which is capable of modeling experimental results accurately.

Table 3 Earthquake records

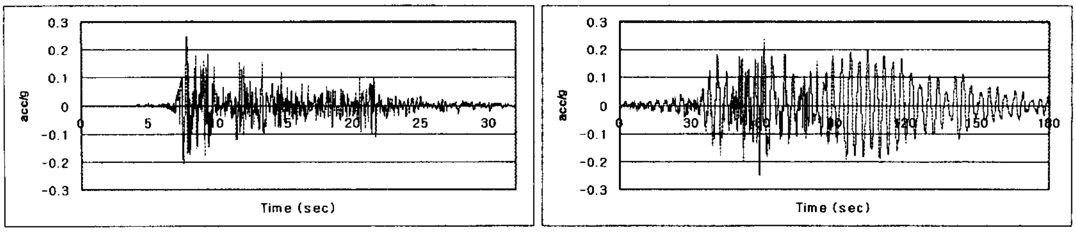
EQ	Date	Peak a/g	Scaled peak acc/g
Imperial Valley	May 18, 1940	0.29	0.25
Mexico City	Sep. 19, 1995	0.10	0.25
Loma Prieta	Oct. 17, 1989	0.27	0.25
Kern County	July 21, 1952	0.16	0.25

5. DISCUSSION OF RESULTS

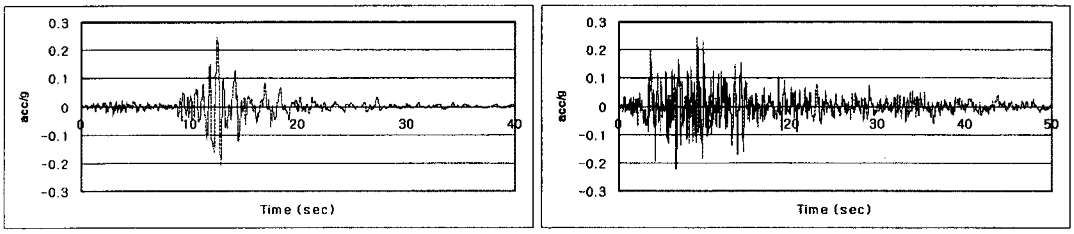
Maximum deflections at the top of building were compared in Fig. 9. For the purpose of comparison, top deflections were normalized with the top deflection value of the building with type A joint.

It was found that the system showed almost identical results except for the Mexican earthquake. Five and ten stories buildings were the most vulnerable to the Mexico earthquake among the others. It is apparent that those buildings moved toward critical response periods as they were loosened by the initial ground motions. However, the Mexico earthquake was scaled up from 0.1g to 0.25g.

The energy dissipation capacities (see Fig. 10) showed a similar trend as the top deflection behavior. The amounts of energy dissipated were almost identical except for the Mexico earthquake.

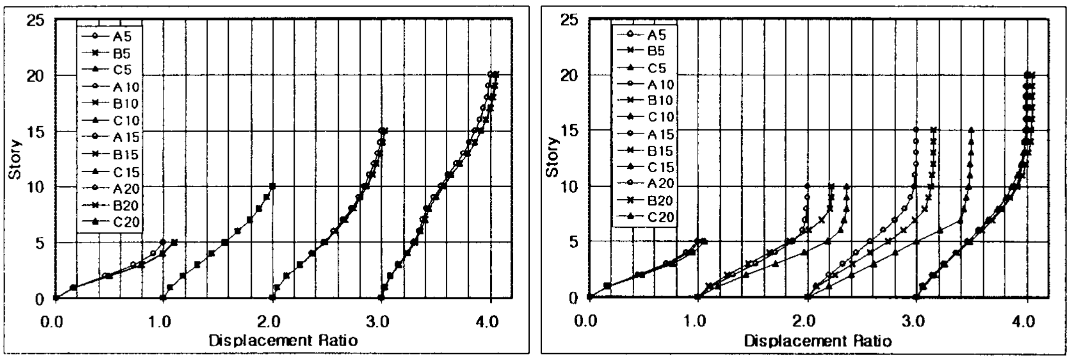


(a) El Centro Earthquake, May 18, 1940 (b) Mexico City Earthquake, September 19, 1995

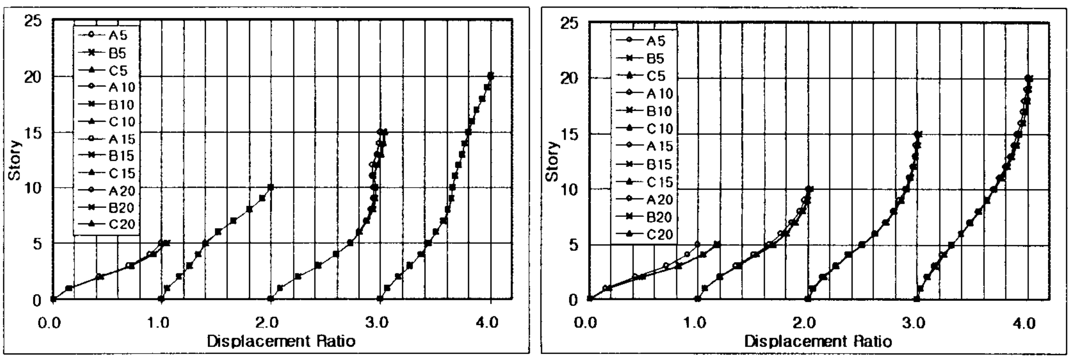


(c) Loma Prieta Earthquake, October 17, 1989 (d) Kern County Earthquake, July 21, 1952

Fig.8 Earthquake records

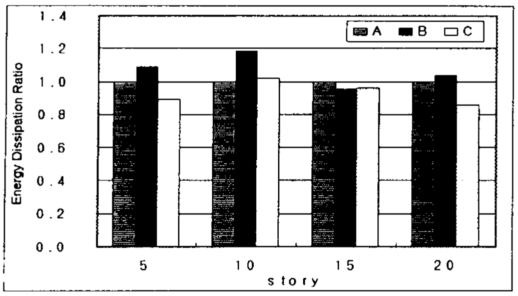


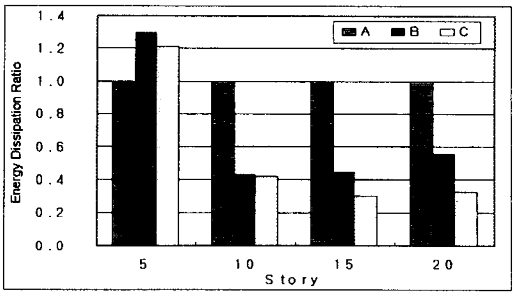
(a) El Centro Earthquake, May 18, 1940 (b) Mexico City Earthquake, September 19, 1995



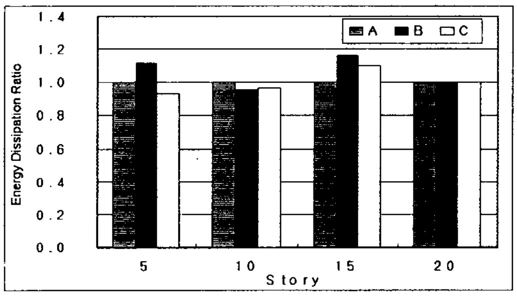
(c) Loma Prieta Earthquake, October 17, 1989 (d) Kern County Earthquake, July 21, 1952

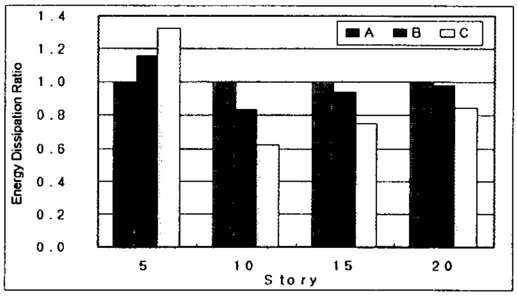
Fig.9 Maximum displacements





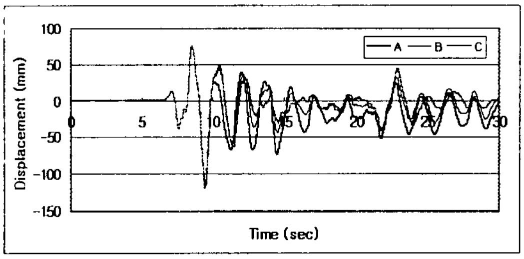
(a) El Centro EarthquaKe, May 18, 1940 (b) Mexico City EarthquaKe, September 19, 1995

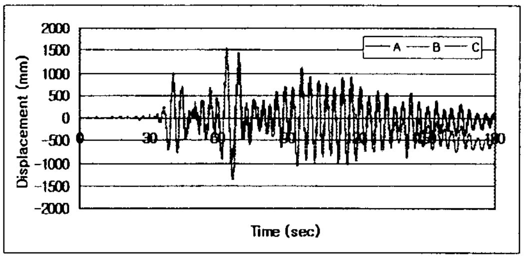




(c) Loma Prieta EarthquaKe, October 17, 1989 (d) Kern County EarthquaKe, July 21, 1952

Fig.10 Energy dissipation





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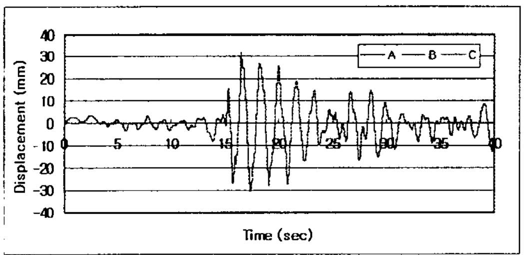

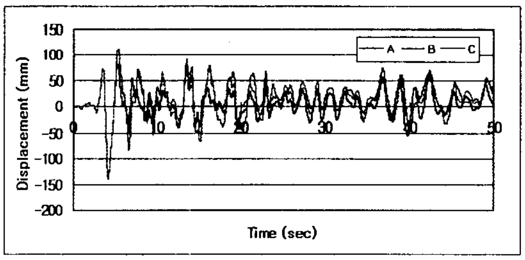

(c) Loma Prieta EarthquaKe, October 17, 1989 (d) Kern County EarthquaKe, July 21, 1952

Fig.11 Response history for 20-story buildings

However, buildings with type B and type C joints revealed low level of energy dissipation capacity.

Fig. 11 illustrates the time-history responses for earthquakes. The frame with hybrid connections exhibits a stable response.

6. CONCLUDING REMARKS

A precast concrete frame system with hybrid beam-column connections was proposed and an analytical study was carried out to evaluate the system under seismic loadings. Three types of joint details were used at four different analytical buildings. Four earthquake records were used as input ground motions. All the records were normalized to the intensity of 0.25g to assess the behavior under the same intensity of seismic excitation.

All the type of joints showed almost identical results except for Mexico earthquake. Buildings with type C joint showed the largest deflection for the Mexico earthquake. Thus, it can be said that type B could be used in a high seismic zone since it would behave as equally as the monolithic system. Type C joint could also be used in the region of low to medium earthquake. Further research is needed to develop design method and various case study.

ACKNOWLEDGEMENT

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REFERENCES

1. G. S. Cheok, H. S. Lew, "Performance of Precast Concrete Beam-to-Column Connections Subject to Cyclic Loading", PCI Journal, May 1991, pp.56-67.
2. G. S. Cheok, H. S. Lew, "Model Precast Concrete Beam-to-Column Connections Subject to Cyclic Loading", PCI Journal, July 1993, pp.80-92.
3. M. J. N. Priestley, G. A. MacRae, "Seismic Tests of Precast Beam-to-Column Joints Subassemblages with Unbonded Tendons", PCI Journal Jan.-Feb. 1996, pp. 64-81.
4. W. C. Stone, G. S. Cheok, J. F. Stanton, "Performance of Hybrid Moment-Resisting Precast Beam-Column Concrete Connections Subject to Cyclic Loading", ACI Structural Journal, Mar. 1995, pp. 229-249.
5. M. J. N. Priestley and G. A. MacRae, "Seismic Tests of Precast Beam-to-Column Joint Subassemblages With Unbonded Tendons," PCI Journal, Jan.-Feb. 1996.
6. J. F. Stanton., W. C. Stone, G. S. Cheok, "A Hybrid Reinforced Precast Frame for Seismic Regions", PCI Journal, Mar.-Apr. 1997.
7. G. S. Cheok, W. C. Stone, S. K. Kunnath, "Seismic Response of Precast Concrete Frames with Hybrid Connections", ACI Structural Journal, May 1998, pp. 527-539.
8. STRESS(advanced STructure RESearch Station), Samsung, "Development and Performance Evaluation of Hybrid Structure with HI-Beams", Technical Report, Dec. 1998.