

석사학위논문

면진용 교좌장치의 내진성능 비교

박규식 (朴圭植)

토목공학과

한국과학기술원

2000

**A Comparative Study on
Aseismic Performance of Bridge Bearings**

A Comparative Study on Aseismic Performance of Bridge Bearings

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A thesis submitted to the faculty of the Korea Advanced Institute of Science and Technology in partial fulfillment of the requirements for the degree of Master of Engineering in the Department of Civil Engineering.

Taejon, Korea

1999. 12. 27.

Approved by

Professor In-Won Lee

Major Advisor

1999 12 27

MCE
983205

. Kyu-Sik Park. A Comparative Study on Aseismic
Performance of Bridge Bearings.

. Department of Civil Engineering. 2000. 56p.
Advisor : Professor In-Won Lee.

ABSTRACT

A comparative study on aseismic performance of bearings for multi-span bridge is carried out. Several leading bridge bearings, such as the LRB(Laminated Rubber Bearing) system, the P-F(Pure-Friction) system, the R-FBI(Resilient-Friction Base Isolation) system and the EDF(Electricité De France) system are considered. Several sensitivity analyses for variations in natural period, friction coefficient are performed. The maximum responses of the center pier, namely the displacement of deck, the deformation of bridge bearing, the shear force and the bending moment of pier are obtained by using the accelerogram of the N00W component of El Centro earthquake(1940).

The displacement of deck and the deformation of bridge bearing decrease as natural period decrease and as friction coefficient increase. On the other hand, the shear force and the bending moment of pier increase. The displacement of the R-FBI system is smaller than that of the P-F system, the EDF system and the LRB system. The moment of the LRB system is smaller than that of the EDF system, the P-F system and the R-FBI system.

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1

1.1

1952 Taft , 1971 Pacoima dam , 1985 Mexico , 1994
 Northridge , 1995 Kobe , 1999 921 , Turkey Izmit
 . 20
 . 1999 921
 Turkey Izmit 가 가
 .
 . 가
 . 13
 , 가 16, 17
 . 18 ~ 20 (地震 休止期) .
 1998 3,000
 . 19 ,
 (規模) 3.0 9 . 1936 (: 5.1),
 1978 (: 5.0), 1978 (: 5.2), 1980 (:
 5.0) 4 5.0 .
 (地震 静止期) 가
 가 .
 ,
 . 1988
 Armenia (不在) 25,000
 가 , Armenia 가 Loma Prieta
 62 [10]

가 El Centro

1.2

가

가 가

LRB(Laminated Rubber Bearing) System, P-F(Pure-Friction) System, R-FBI(Resilient-Friction Base Isolation) System, EDF(Electricité De France) System . LRB System

, P-F System

. R-FBI System EDF

System

~

LRB System, P-F System, R-FBI System, EDF System

(Beam Element)

, LRB System

, P-F System

, R-FBI System EDF System

ADINA General Element

Contact Surface Element .

가 El Centro

.

,

,

.

2

2.1

1996

< >

가

[14]

가

가

가

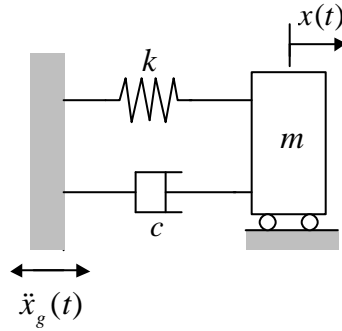
가

2.1

가

(2.1)

[7]



2.1

$$m\ddot{x}(t) + c\dot{x}(t) + kx(t) = -m\ddot{x}_g(t) \tag{2.1}$$

$$(2.1) \tag{2.2}$$

$$x(t) = -\frac{1}{\omega_D} \int_0^t \ddot{x}_g(\tau) e^{-\zeta\omega_n(t-\tau)} \sin \omega_D(t-\tau) d\tau \tag{2.2}$$

ω_n , ζ , ω_D .
 , 가 0.2 $\omega_D \approx \omega_n$.
 (2.3)

$$\max |x(t)| = \frac{1}{\omega_n} \max \left| \int_0^t \ddot{x}_g(\tau) e^{-\zeta\omega_n(t-\tau)} \sin \omega_n(t-\tau) d\tau \right| \tag{2.3}$$

가 ω_n ζ 가
 (2.3) , (2.4) ω_n ζ

(Spectral Relative Displacement; $S_d(\omega_n, \zeta)$) .

$$S_d(\omega_n, \zeta) = \max |x(t)| \tag{2.4}$$

(2.1)

(2.5)

$$m\ddot{x}^t(t) + kx(t) = 0 \quad (2.5)$$

 $\ddot{x}^t(t)$

가

 $[\ddot{x}_g(t) + \ddot{x}(t)]$

(2.4)

(2.5)

가

(2.6)

$$\begin{aligned} \max |\dot{x}^t(t)| &= \frac{k}{m} \max |x(t)| \\ &= \mathbf{w}_n^2 \max |x(t)| = \mathbf{w}_n^2 S_d(\mathbf{w}_n, \mathbf{x}) \end{aligned} \quad (2.6)$$

가 (Spectral Absolute Acceleration; $S_a(\mathbf{w}_n, \mathbf{x})$) (2.7)

$$S_a(\mathbf{w}_n, \mathbf{x}) = \max |\dot{x}^t(t)| = \mathbf{w}_n^2 S_d(\mathbf{w}_n, \mathbf{x}) \quad (2.7)$$

(2.4)

(2.7)

가

가

가

2.2 El Centro

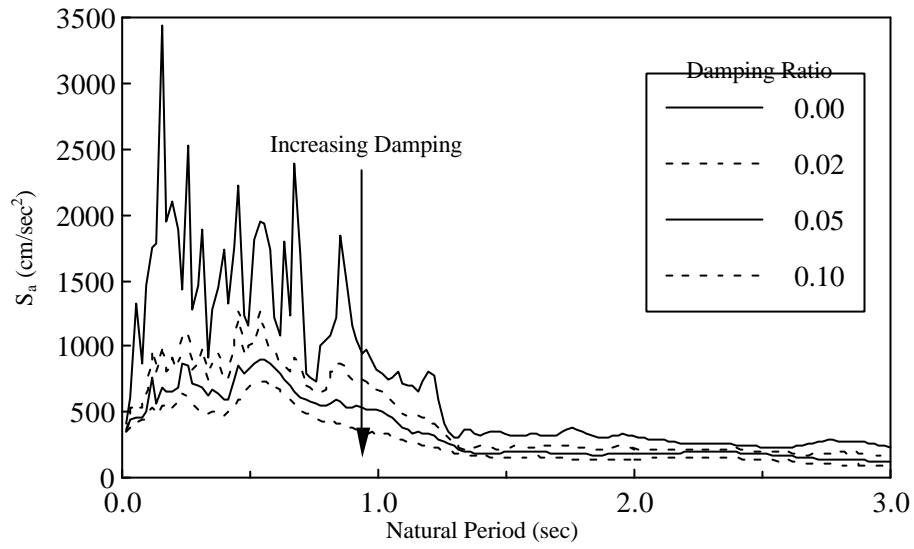
가

가 가

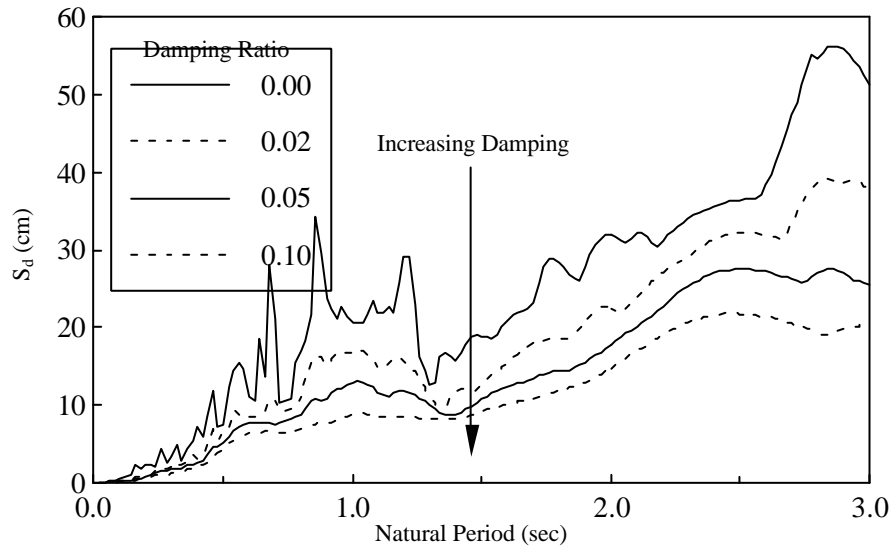
가

가

가 가



(a) 가



(b)

2.2

가 가 가

, 가

가

가

가

가

(Hysteretic Damping)

가

가

가

2.2.1 LRB(Laminated Rubber Bearing) System^{[1],[13]}

LRB System

2.3

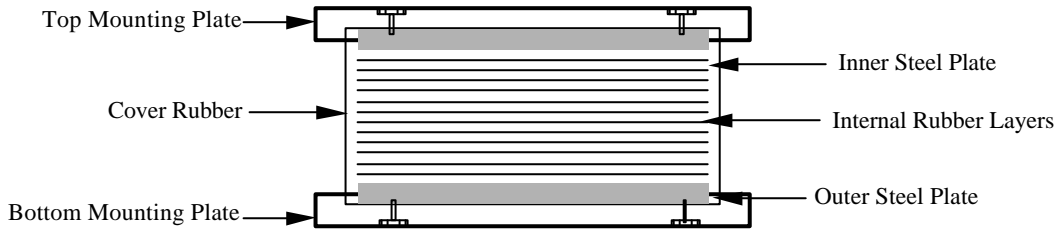
(Steel Plate)

가

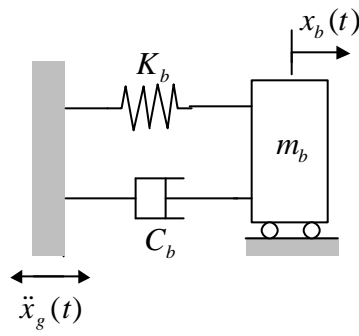
가

LRB System

2.4



2.3 LRB System



2.4 LRB System

2.4 LRB System $\ddot{x}_g(t)$

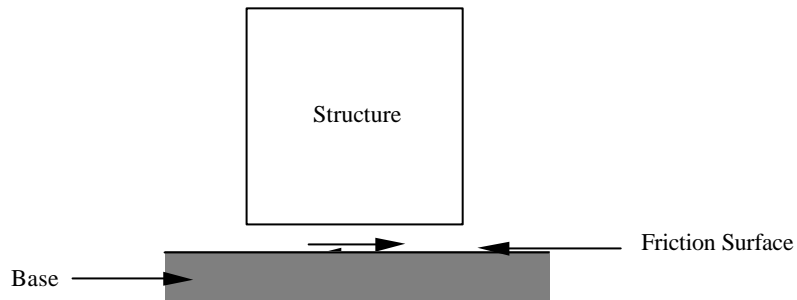
(2.8)

$$M\ddot{x}_b(t) + C_b\dot{x}_b(t) + K_b x_b(t) + \sum_{n=1}^N m_n a_n = -M\ddot{x}_g(t) \tag{2.8}$$

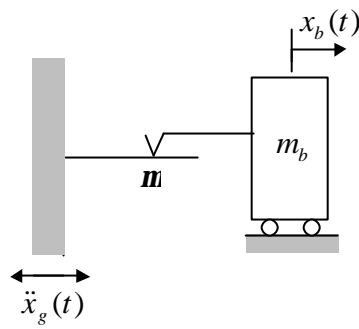
M , C_b , K_b , N 가 a_n

2.2.2 P-F(Pure-Friction) System^{[4], [13]}

P-F System Sliding Joint System
 가
 (Sliding)
 가
 가
 가
 가
 4
 P-F System
 1984
 [1]



2.5 P-F System



2.6 P-F System

Coulomb P-F System (2.9)
 $\dot{x}_b(t) = 0$

$$\left| M\ddot{x}_g(t) + \sum_{n=1}^N m_n a_n \right| < \mathbf{m}Mg \quad (2.9)$$

가 (2.10) 가

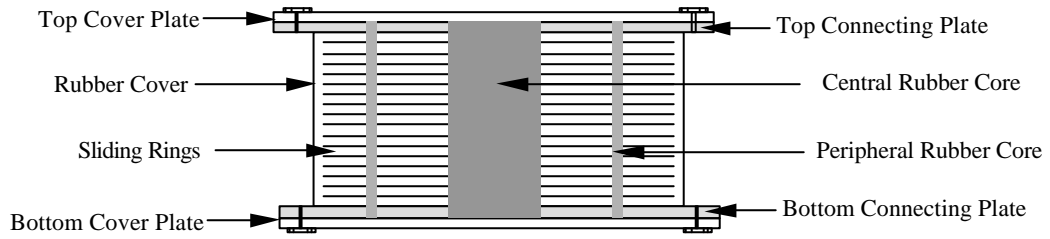
$sign[\dot{x}_b(t)]$ P-F System

$$M\ddot{x}_b(t) + \mathbf{m}Mg sign[\dot{x}_b(t)] + \sum_{n=1}^N m_n a_n = -M\ddot{x}_g(t) \quad (2.10)$$

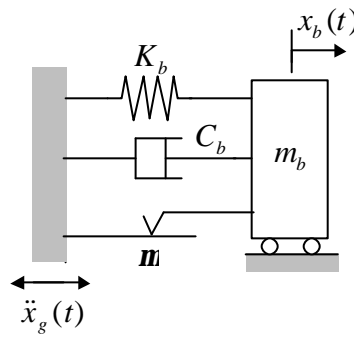
$\dot{x}_b(t) = 0$ 가

2.2.3 R-FBI(Resilient-Friction Base Isolation) System^{[5], [13]}

1984 Mostaghel R-FBI System LRB System
 P-F System 2.7 Teflon
 (Rubber Core) 가 P-F System 가
 가 P-F System
 가 R-FBI System 2.8 , ,
 가



2.7 R-FBI System



2.8 R-FBI System

2.8 R-FBI System (2.11)

P-F System

$$\left| M\ddot{x}_g(t) + K_b x_b(t) + \sum_{n=1}^N m_n a_n \right| < \mathbf{m}Mg \quad (2.11)$$

(2.11)

(2.12)

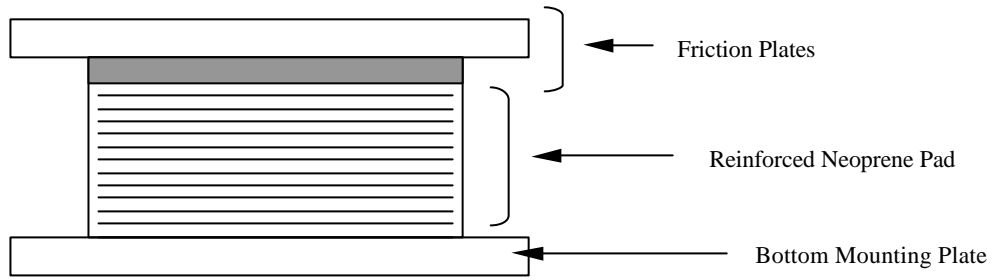
$$M\ddot{x}_b(t) + C_b \dot{x}_b(t) + \mathbf{m}Mg \operatorname{sign}[\dot{x}_b(t)] + K_b x_b(t) + \sum_{n=1}^N m_n a_n = -M\ddot{x}_g(t) \quad (2.12)$$

$$\dot{x}_b(t) = 0$$

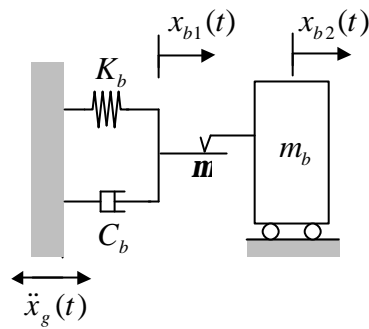
가

2.2.4 EDF(Electricité De France) System^{[1], [13]}

LRB System	P-F System	EDF System
	Neoprene	2.9
		(Lead-Bronze)
	가	가
	Neoprene	가
		가
		가



2.9 EDF System



2.10 EDF System

2.10 , , 가
EDF System , EDF System ,

$\ddot{x}_{b1}(t) = \ddot{x}_{b2}(t), \dot{x}_{b1}(t) = \dot{x}_{b2}(t)$ 가 (2.14) LRB System

가 . $x_{b1}(t)$, $x_{b2}(t)$.

$$\left| M\ddot{x}_g(t) + M\ddot{x}_{b2}(t) + \sum_{n=1}^N m_n a_n \right| < \mathbf{m}Mg \quad (2.13)$$

$$M\ddot{x}_{b2}(t) + C_b \dot{x}_{b2}(t) + K_b x_{b2}(t) + \sum_{n=1}^N m_n a_n = -M\ddot{x}_g(t) \quad (2.14)$$

(2.13)

EDF System (2.15) (2.16)

P-F System 가 .

$$C_b \dot{x}_{b1}(t) + K_b x_{b1}(t) = \mathbf{m}Mg \operatorname{sign}[\dot{x}_{b2}(t) - \dot{x}_{b1}(t)] \quad (2.15)$$

$$M\ddot{x}_{b2}(t) + \mathbf{m}Mg \operatorname{sign}[\dot{x}_{b2}(t) - \dot{x}_{b1}(t)] + \sum_{n=1}^N m_n a_n = -M\ddot{x}_g(t) \quad (2.16)$$

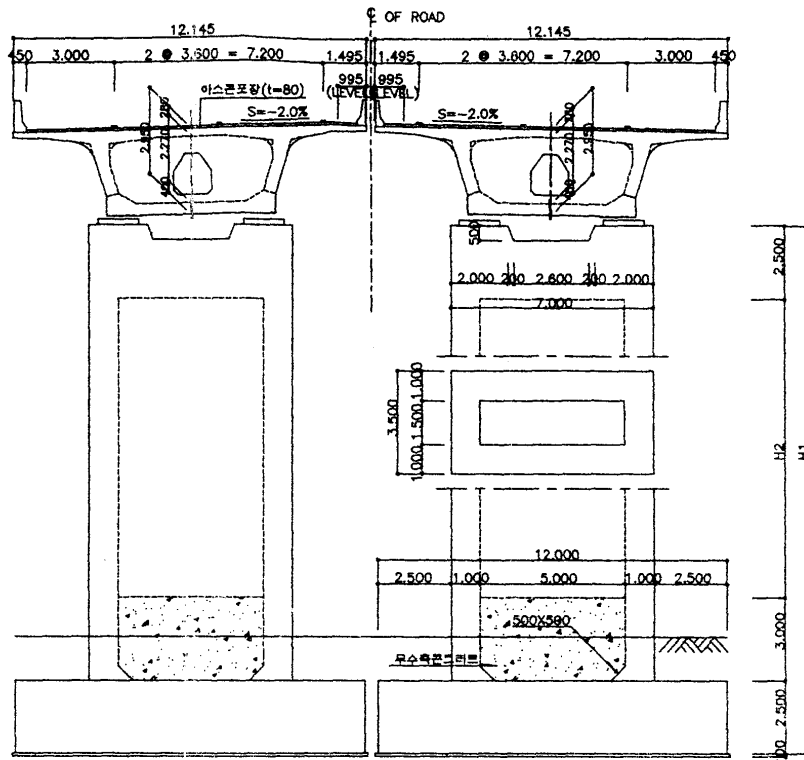
$\dot{x}_{b2}(t) = 0$ 가 .

3

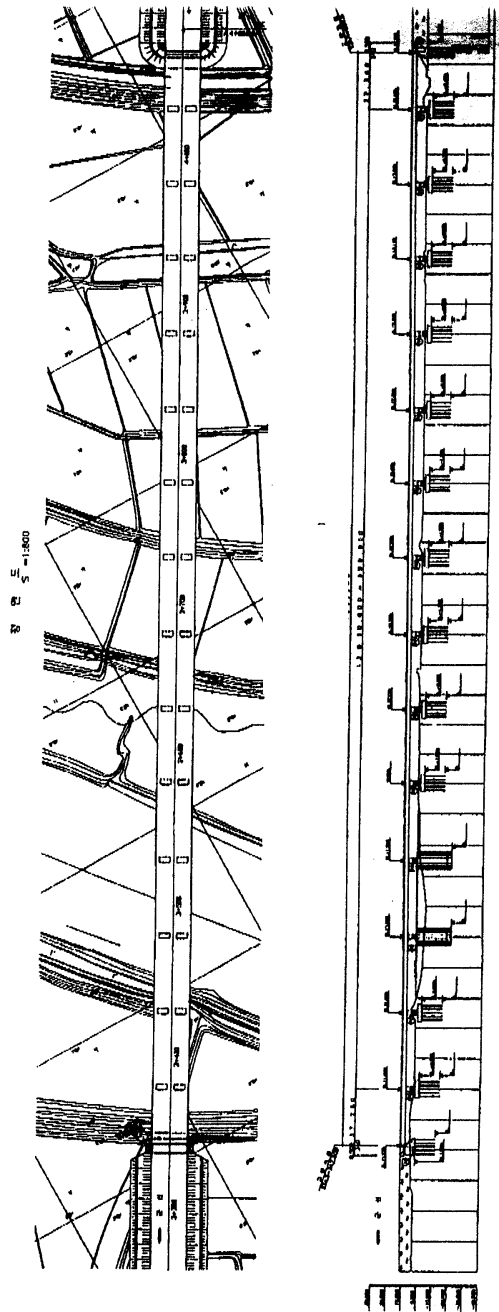
3.1

3.1.1

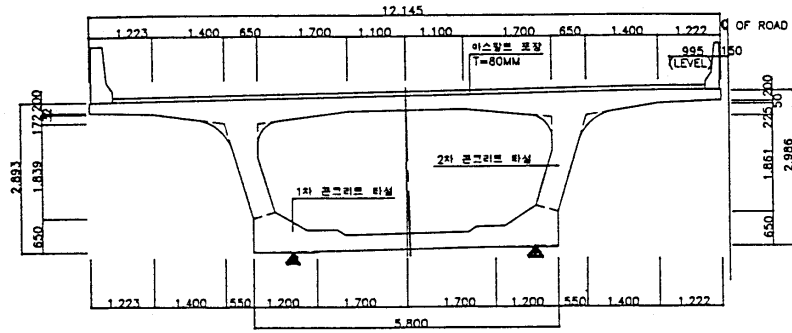
~ PSC Box Girder 15
 725m, 12.145m 0.03% 가 .
 LRB(Laminated Rubber Bearing) System 3.1 ~
 3.3



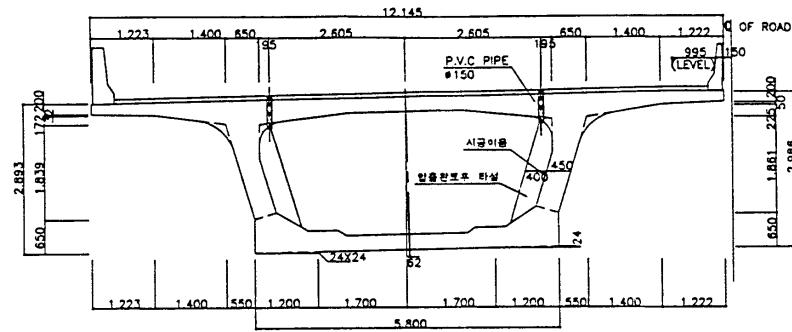
3.1



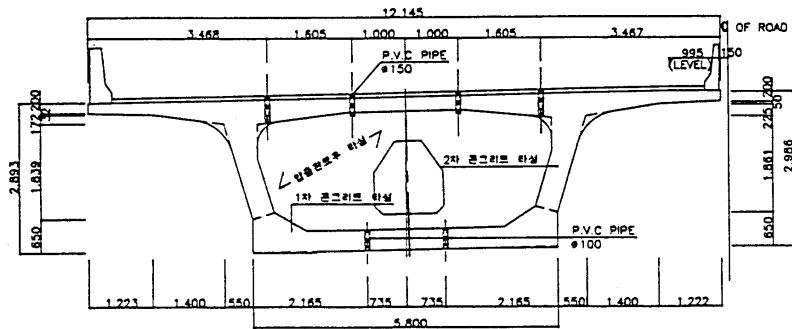
3.2



(a)



(b)



(c)

3.3

PSC 2 ~ 3%
 2%
 Rayleigh Damping [7]
 (3.1) n (Mode) \mathbf{x}_n (3.2)
 M, C, K , , , \mathbf{a}, \mathbf{b} Rayleigh
 Damping , \mathbf{w}_n

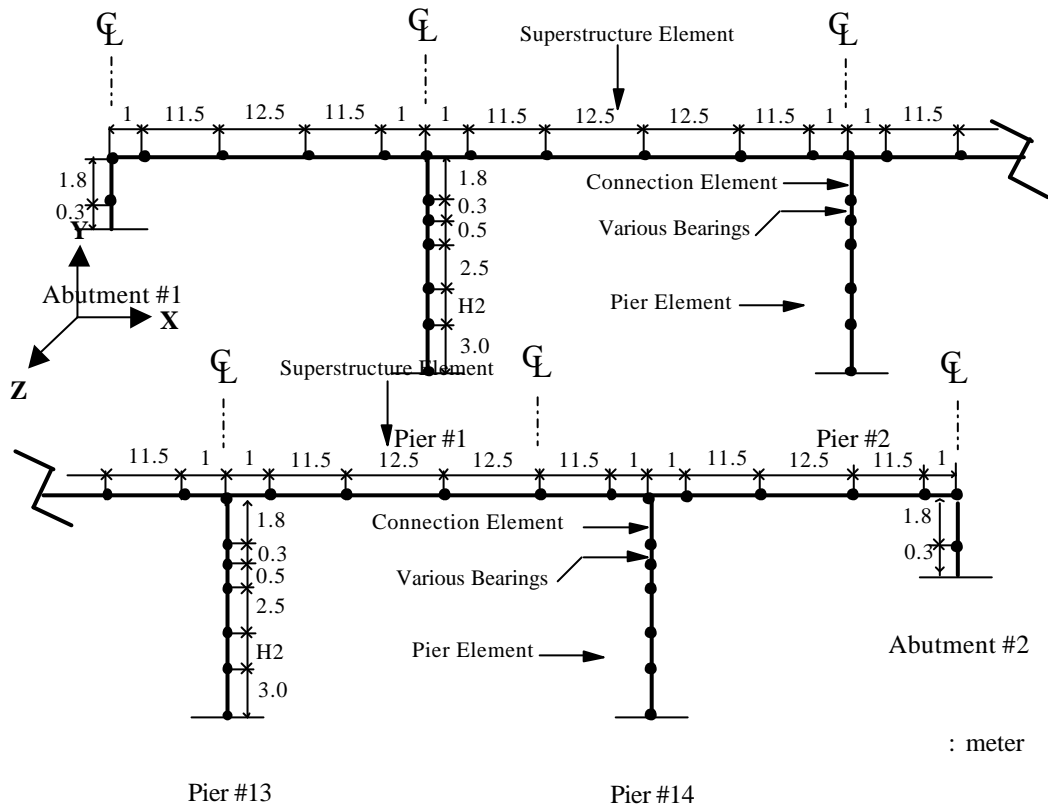
$$C = \mathbf{a}M + \mathbf{b}K \tag{3.1}$$

$$\mathbf{x}_n = \frac{C}{\sqrt{2MK}} = \frac{\mathbf{a}}{2\mathbf{w}_n} + \frac{\mathbf{b}\mathbf{w}_n}{2} \tag{3.2}$$

i j $\mathbf{x}_i, \mathbf{x}_j$
 (3.3) i j 가 \mathbf{x} Rayleigh
 Damping (3.4)

$$\begin{bmatrix} \mathbf{x}_i \\ \mathbf{x}_j \end{bmatrix} = \frac{1}{2} \begin{bmatrix} 1/\mathbf{w}_i & \mathbf{w}_i \\ 1/\mathbf{w}_j & \mathbf{w}_j \end{bmatrix} \begin{bmatrix} \mathbf{a} \\ \mathbf{b} \end{bmatrix} \tag{3.3}$$

$$\mathbf{a} = \frac{2\mathbf{x}\mathbf{w}_i\mathbf{w}_j}{\mathbf{w}_i + \mathbf{w}_j}, \mathbf{b} = \frac{2\mathbf{x}}{\mathbf{w}_i + \mathbf{w}_j} \tag{3.4}$$



3.4

3.1 (H2)

	P1	P2	P3	P4	P5	P6	P7
H2(m)	0.94	1.09	1.21	1.33	1.46	1.57	1.98
	P8	P9	P10	P11	P12	P13	P14
H2(m)	2.13	2.08	2.13	2.32	2.36	2.40	2.48

3.2

	A (m ²)	E (GPa)	ρ (kg/m ³)	I (m ⁴)	I (m ⁴)	J (m ⁴)
1	8.62	27.50	2300	80.67	11.06	19.48
2	9.95	27.50	2300	88.71	11.54	20.87
3	18.24	27.50	2300	105.70	15.44	34.66
1	14.00	23.24	2300	92.71	14.29	11.87
2	24.50	23.24	2300	100.00	25.01	66.73
3	17.00	23.24	2300	84.42	23.60	52.94

3.1.2

[6]

3.1.2.1 LRB(Laminated Rubber Bearing) System

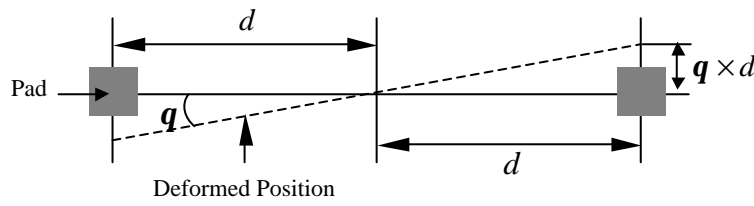
LRB System 3.3
 LRB System .

3.3 LRB System

100cm×120cm×30cm	70cm×85cm×30cm
20mm×11	20mm×11
5mm×2	5mm×10
15mm×2	15mm×2
1.575×10^9 N/m	5.386×10^9 N/m
2.658×10^6 N/m	5.351×10^6 N/m

LRB System

3.5 $q = 1rad$ 가 LRB System Pad (3.5) LRB System (3.6) LRB System



3.5

$$V = K_{trans} \times q \times d \tag{3.5}$$

$$M = V \times 2d \tag{3.6}$$

$$K_{rot} = \frac{M}{q} = K_{trans} \times 2d^2 \tag{3.7}$$

K_{trans} , K_{rot} LRB System

(3.8)

$$C_{ht} = 2x\sqrt{mK_{ht}} \tag{3.8}$$

x $x = 10\%$ 가

m LRB System, K_{ht}

LRB System (3.7), (3.8) LRB System

3.4

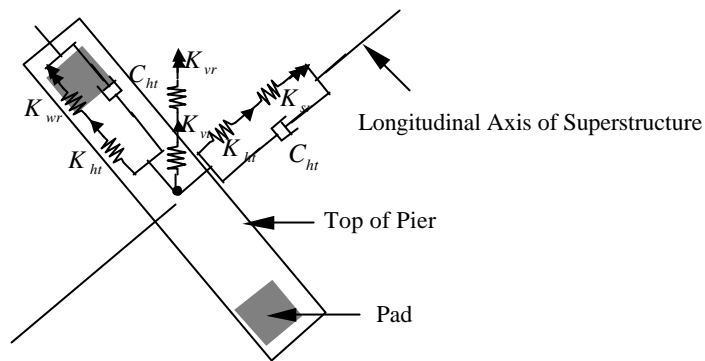
3.4 LRB System

	K_{ht}	5.315×10^6	1.070×10^7
(N/m)	K_{vt}	3.150×10^9	1.077×10^{10}
	K_{sr}	1.814×10^{10}	6.204×10^{10}
(N·m/rad)	K_{vr}	3.061×10^7	6.165×10^7
	K_{wr}	0	0
(N·sec/m)	C_{ht}	2.858×10^5	6.657×10^5

K_{vt} , K_{sr} ,
 K_{vr} , K_{wr} ,

3.4

3.6



3.6 LRB System

LRB System

. LRB System

ADINA General Element

3.1.2.2 P-F(Pure-Friction) System

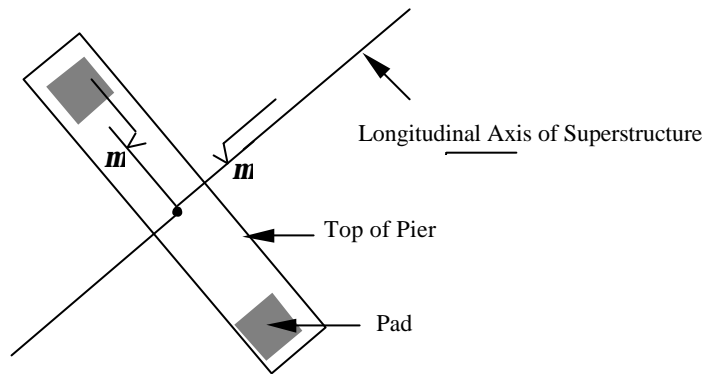
P-F System

가

가

. P-F System

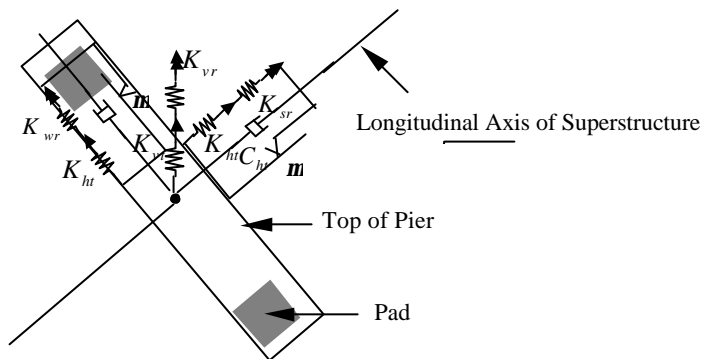
ADINA Contact Surface Element



3.7 P-F System

3.1.2.3 R-FBI(Resilient-Friction Base Isolation) System

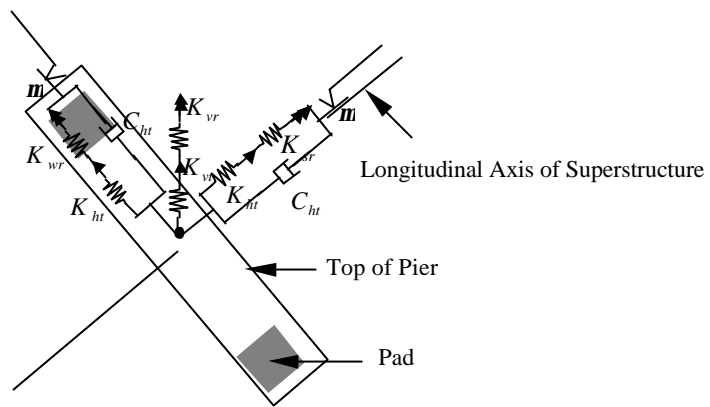
R-FBI System	LRB System	3.8
,	가	.



3.8 R-FBI System

3.1.2.4 EDF(Electricité De France) System

EDF System	LRB System	3.9
,	가	.



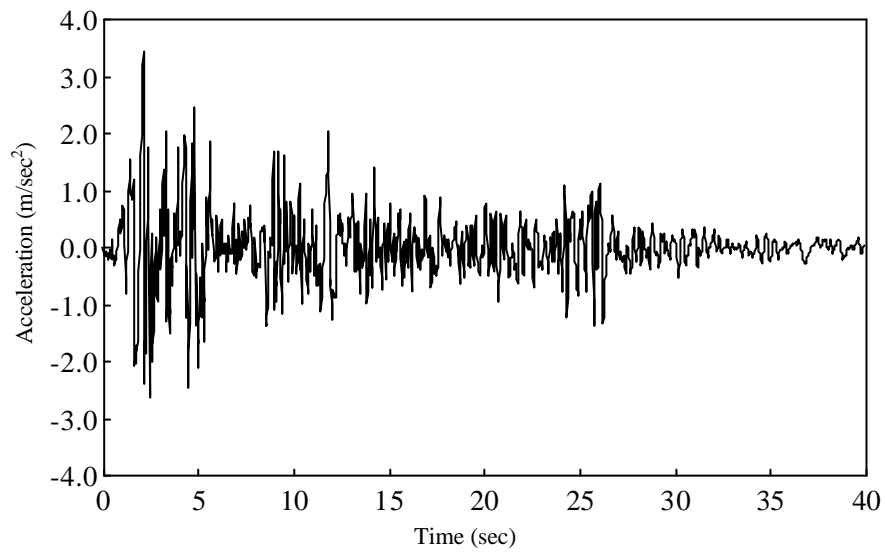
3.9 EDF System

3.2

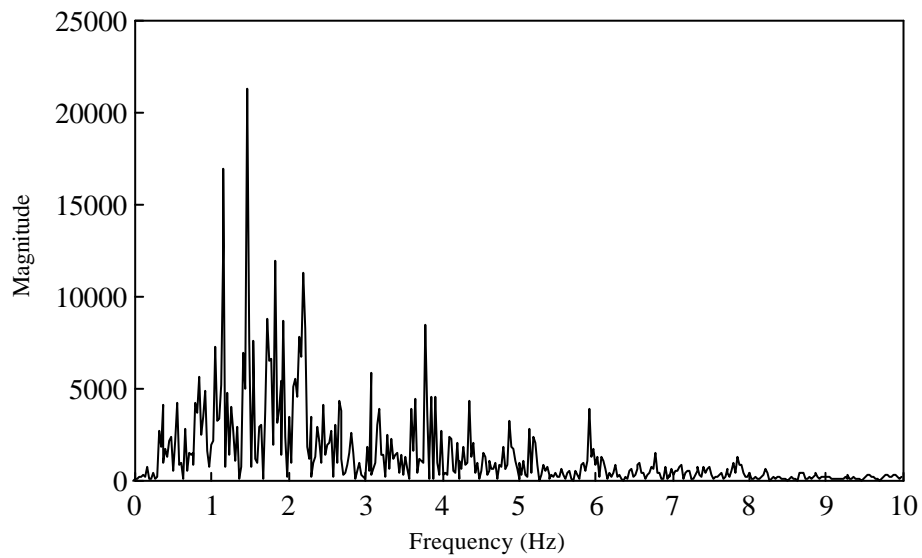
3.2.1

1940 California Imperial El Centro
 N00W . El Centro 가 .
 가 0.348g 2 1
 ~ 4Hz 1.46Hz . El Centro
 가
 . El
 Centro

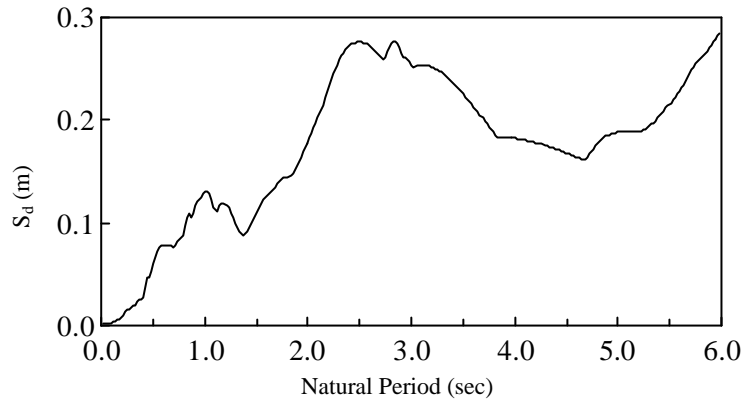
1984 MIT K. J. Bathe
 ADINA(Automatic Dynamic Incremental Nonlinear Analysis)
 . ADINA (Structure), (Heat Transfer), (Fluid Flow), -
 (Fluid-Structure Interaction) (Static), (Dynamic)
 (Linear), (Nonlinear) 가
 (Contact Problem) Contact Surface Element



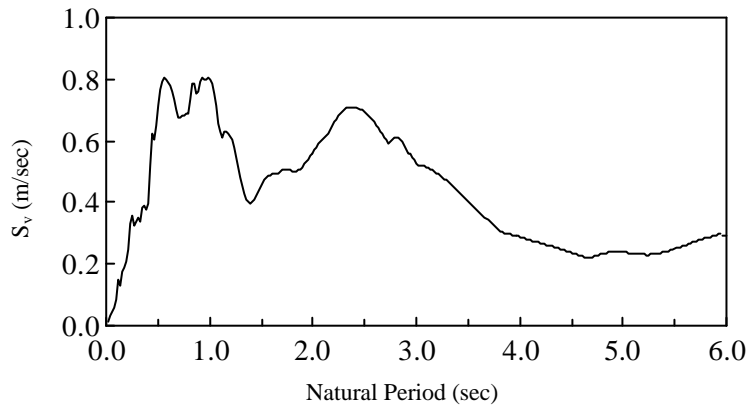
3.10 El Centro 가



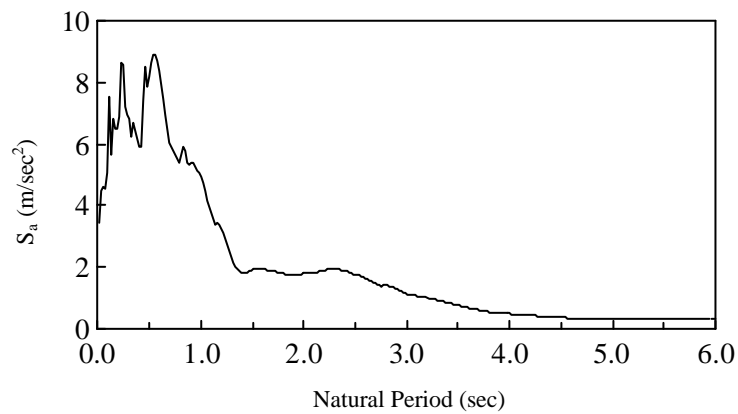
3.11 El Centro Fourier Spectrum



(a)



(b)



(c) 가

3.12 El Centro

 $(\alpha = 0.05)$

3.2.2

가 가

가

El Centro

1.0 ~ 6.0 0.5

0.02 ~ 0.30 0.02

가

가

가

가 (7)

3.2.2.1 LRB(Laminated Rubber Bearing) System

LRB System

LRB System K_{ht}

3.7 3.8

K_{vr} C_{ht} 가 3.5

LRB System

LRB System

LRB System

LRB System

70%,

150% <KS F 4420>

< >

LRB System

30cm,

33cm

34cm

3.5

Natural Period (sec)	Displacement (cm)		Deformation (cm)		Shear ($\times 10^6$ N)		Moment ($\times 10^6$ N×m)	
	long.*	trans.**	long.	trans.	Long.	trans.	long.	trans.
1.0	7.39	8.02	7.31	8.00	3.22	2.32	19.85	14.06
1.5	8.01	8.37	7.98	8.36	1.58	1.32	9.88	7.61
2.0	12.50	14.11	12.47	14.10	1.49	1.28	8.88	7.49
2.5	19.45	19.40	19.42	19.39	1.37	1.15	8.27	6.39
3.0	17.53	19.21	17.52	19.21	1.34	1.06	7.40	5.58
3.5	18.86	16.73	18.85	16.73	1.17	1.04	6.30	5.48
4.0	15.64	14.38	15.63	14.38	1.01	0.97	4.71	4.64
4.5	14.62	13.23	14.62	13.23	0.98	0.96	4.52	4.31
5.0	13.52	13.68	13.52	13.68	0.96	0.94	4.35	4.20
5.5	14.03	14.22	14.03	14.22	0.93	0.92	4.20	4.10
6.0	14.50	14.56	14.50	14.56	0.91	0.90	4.07	4.00

*, **:

가 가

가,

가

3.12

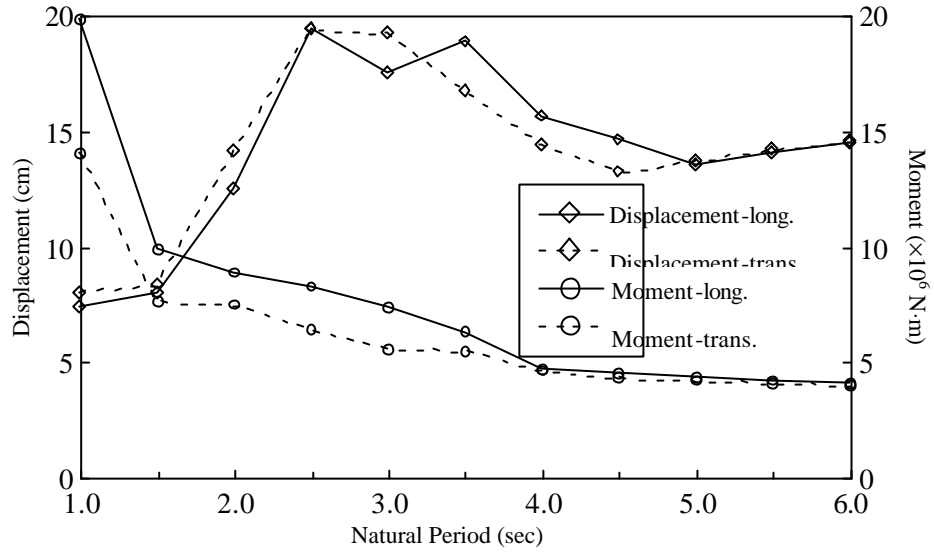
El Centro

가 가

LRB System

가 가

3.13



3.13

3.2.2.2 P-F(Pure-Friction) System

P-F System 0.02 ~

0.30 0.02 . 3.6 .

3.6 3.14 가 가

가 . P-F System

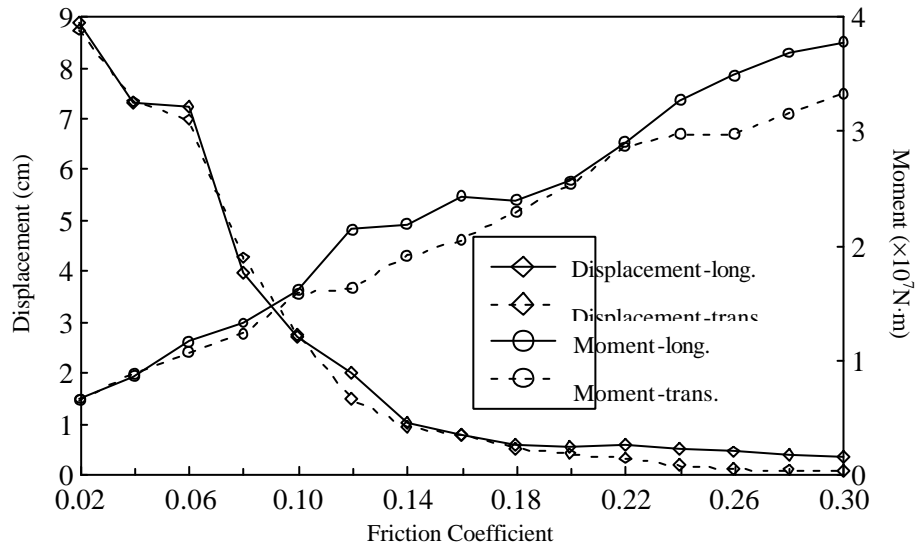
 . 가 가

 가 . P-F System

 가

3.6

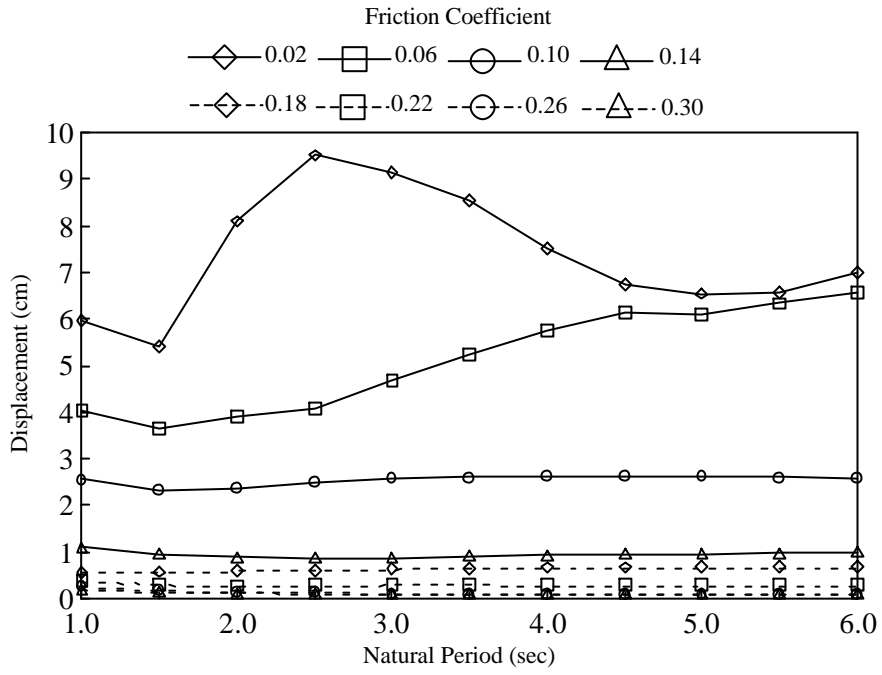
Friction Coefficient	Displacement (cm)		Deformation (cm)		Shear ($\times 10^6$ N)		Moment ($\times 10^7$ N.m)	
	long.	trans.	long.	Trans.	long.	trans.	long.	trans.
0.02	8.86	8.73	8.86	8.73	1.23	1.25	0.66	0.65
0.04	7.31	7.32	7.29	7.31	1.51	1.55	0.86	0.88
0.06	7.22	6.97	7.20	6.97	1.95	1.79	1.16	1.07
0.08	3.97	4.26	3.95	4.26	2.09	1.97	1.32	1.23
0.10	2.71	2.76	2.69	2.75	2.56	1.52	1.61	1.58
0.12	1.99	1.48	1.95	1.47	3.29	2.55	2.14	1.63
0.14	1.03	0.95	0.99	0.94	3.38	2.95	2.18	1.91
0.16	0.78	0.78	0.74	0.77	3.73	3.14	2.43	2.05
0.18	0.60	0.52	0.53	0.50	3.62	3.46	2.39	2.29
0.20	0.54	0.41	0.47	0.39	3.70	3.72	2.56	2.53
0.22	0.60	0.33	0.52	0.31	4.18	4.15	2.90	2.86
0.24	0.51	0.18	0.42	0.16	4.77	4.26	3.27	2.97
0.26	0.45	0.11	0.35	0.09	5.08	4.30	3.48	2.97
0.28	0.40	0.10	0.31	0.07	5.36	4.55	3.68	3.15
0.30	0.36	0.09	0.24	0.06	5.44	4.78	3.77	3.32



3.14

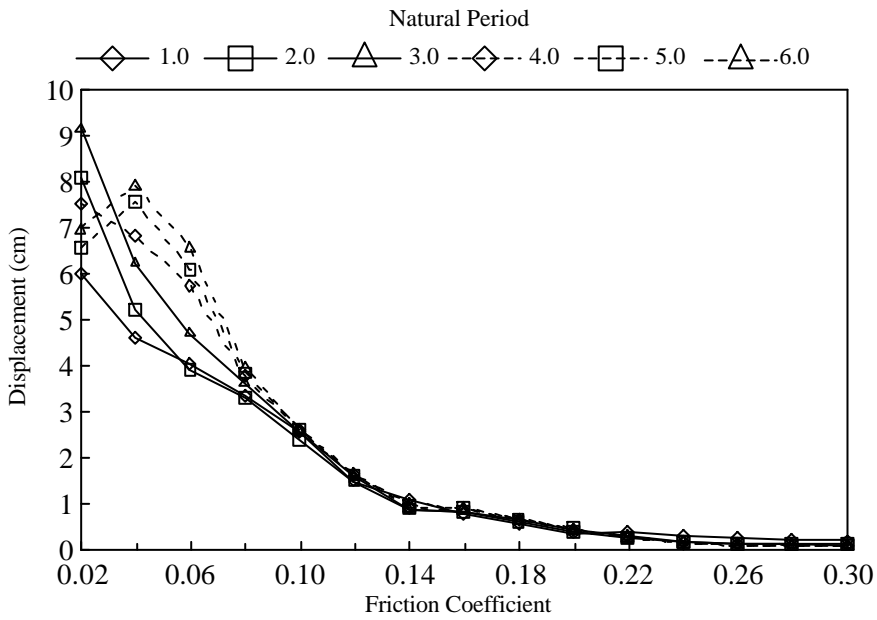
3.2.2.3 R-FBI(Resilient-Friction Base Isolation) System

R-FBI System		R-FBI System	
	3.7 ~		3.10
	가		가
			3.15
3.16	가		
	가		가
		P-F System	가
P-F System			가
	3.11 ~		3.14
	가		가
	가		가
		LRB System	가
		P-F System	가
가	P-F System		가



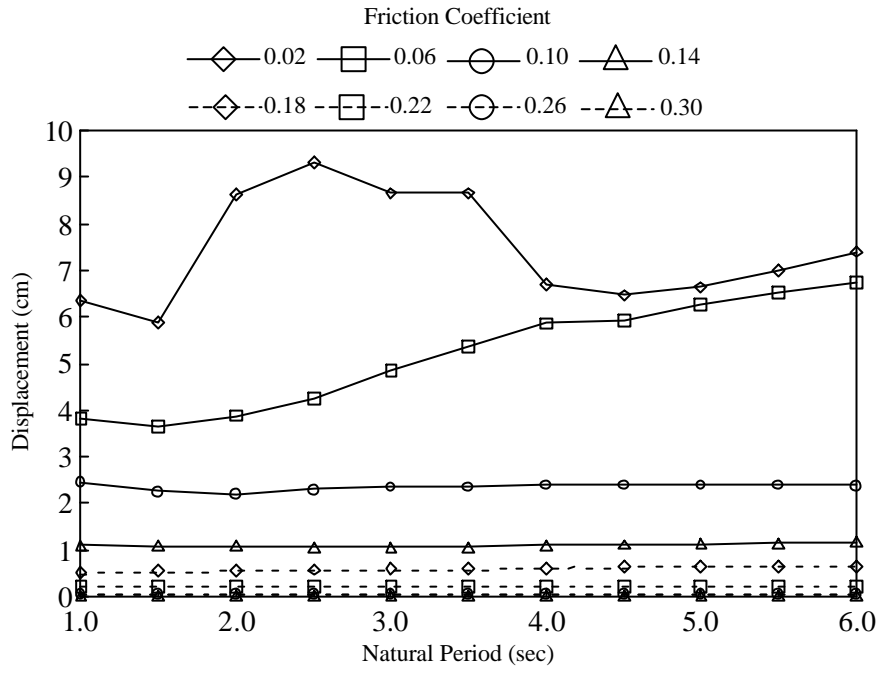
3.15

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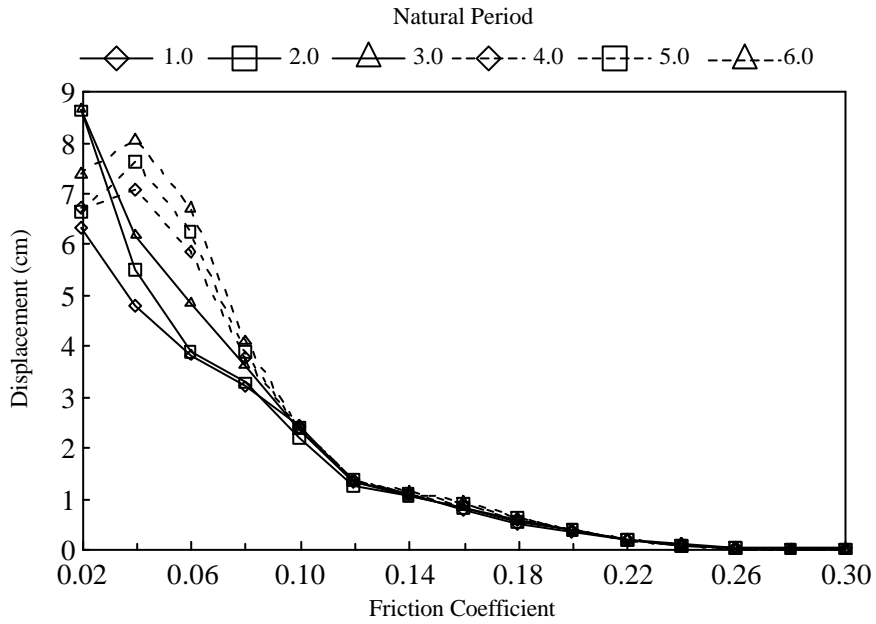
3.16

;



3.17

;



3.18

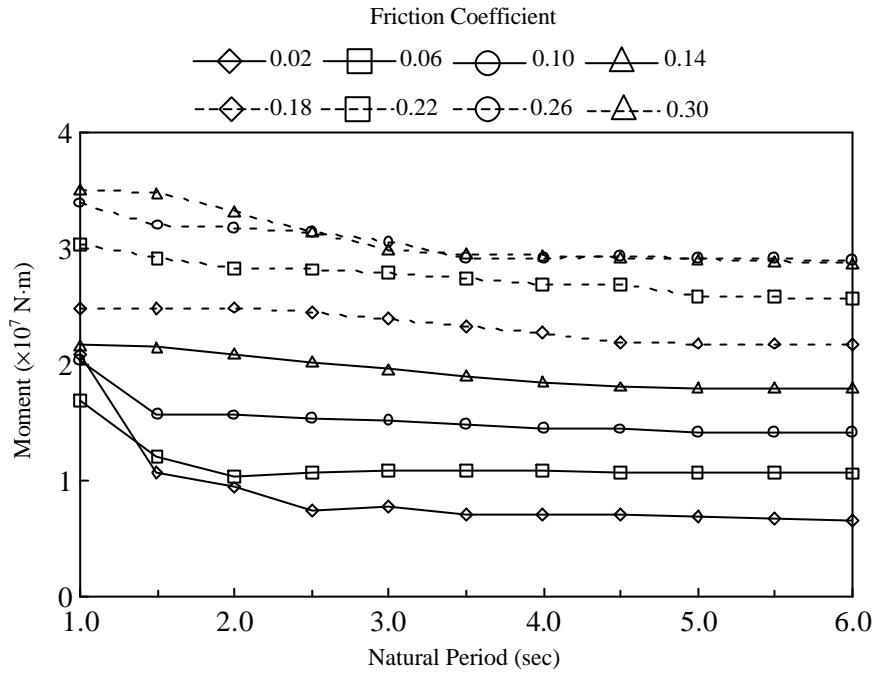
;

		3.11										
		($\cdot 10^6$ N);										
$m \backslash T$		1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
0.02		2.86	1.58	1.28	1.26	1.31	1.31	1.31	1.29	1.28	1.24	1.23
0.04		2.49	1.62	1.53	1.59	1.62	1.62	1.61	1.59	1.57	1.55	1.53
0.06		2.37	1.89	1.67	1.78	1.81	1.81	1.79	1.81	1.81	1.80	1.78
0.08		2.55	2.20	2.06	2.02	2.07	2.07	2.04	2.00	1.98	1.98	1.98
0.10		3.00	2.48	2.45	2.36	2.31	2.29	2.27	2.26	2.26	2.25	2.25
0.12		3.01	2.89	2.83	2.76	2.69	2.59	2.56	2.54	2.53	2.52	2.51
0.14		3.16	3.14	3.05	2.96	2.87	2.79	2.77	2.77	2.77	2.76	2.76
0.16		3.34	3.21	3.18	3.13	3.09	3.05	3.02	3.02	3.02	3.02	3.01
0.18		3.53	3.51	3.52	3.45	3.38	3.30	3.27	3.27	3.27	3.27	3.26
0.20		3.71	3.65	3.65	3.64	3.55	3.54	3.56	3.57	3.57	3.56	3.54
0.22		4.25	4.08	3.93	3.91	3.88	3.85	3.85	3.83	3.82	3.81	3.80
0.24		4.69	4.33	4.24	4.16	4.12	4.11	4.10	4.09	4.08	4.06	4.04
0.26		4.78	4.59	4.56	4.50	4.39	4.27	4.26	4.25	4.24	4.23	4.21
0.28		4.81	4.76	4.70	4.58	4.35	4.32	4.30	4.28	4.26	4.23	4.21
0.30		5.01	4.98	4.76	4.51	4.32	4.31	4.29	4.27	4.25	4.22	4.20

		3.12										
		($\cdot 10^6$ N);										
$m \backslash T$		1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
0.02		3.05	1.62	1.42	1.26	1.32	1.32	1.32	1.31	1.29	1.23	1.25
0.04		2.60	1.68	1.51	1.58	1.60	1.60	1.58	1.56	1.54	1.52	1.50
0.06		2.39	1.80	1.70	1.76	1.78	1.78	1.79	1.81	1.81	1.79	1.76
0.08		2.75	2.17	2.02	2.03	2.04	2.03	2.01	1.97	1.97	1.98	1.98
0.10		2.94	2.44	2.43	2.37	2.34	2.34	2.29	2.28	2.27	2.26	2.26
0.12		2.85	2.87	2.82	2.74	2.67	2.67	2.53	2.53	2.52	2.51	2.50
0.14		3.10	3.00	2.94	2.88	2.84	2.84	2.80	2.79	2.78	2.77	2.76
0.16		3.25	3.16	3.12	3.11	3.07	3.07	3.05	3.04	3.03	3.02	3.02
0.18		3.49	3.49	3.47	3.42	3.35	3.35	3.31	3.31	3.29	3.28	3.27
0.20		3.77	3.72	3.75	3.78	3.73	3.59	3.55	3.54	3.53	3.53	3.52
0.22		4.57	4.29	4.01	3.83	3.83	3.82	3.82	3.81	3.80	3.79	3.78
0.24		4.45	4.40	4.43	4.37	4.23	4.10	4.09	4.08	4.07	4.06	4.04
0.26		4.38	4.36	4.35	4.34	4.32	4.31	4.29	4.27	4.25	4.23	4.21
0.28		4.50	4.51	4.49	4.47	4.45	4.43	4.41	4.39	4.36	4.34	4.31
0.30		4.50	4.51	4.49	4.47	4.45	4.43	4.41	4.39	4.36	4.34	4.31

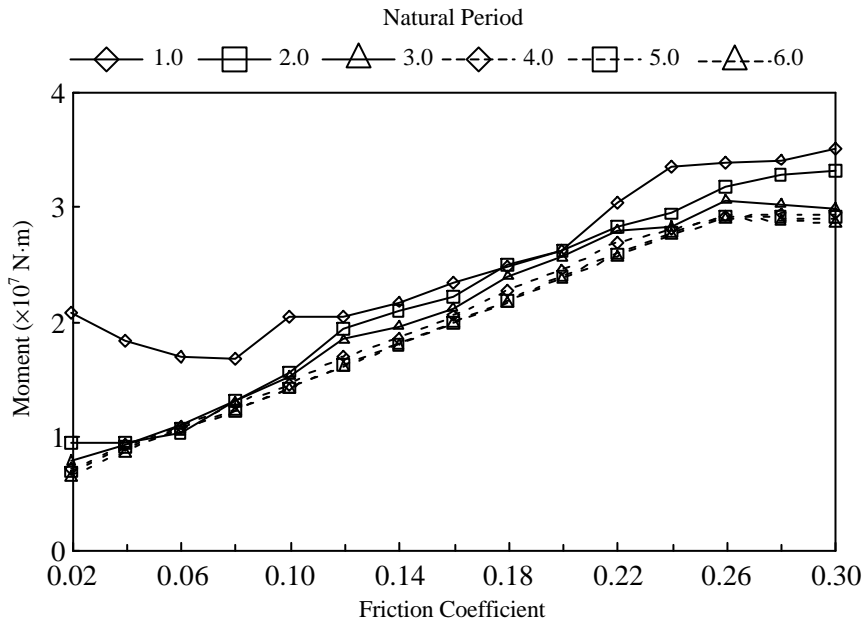
		3.13										
		($\cdot 10^7 \text{ N}\cdot\text{m}$);										
$m \backslash T$	T	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
0.02		2.08	1.07	0.94	0.74	0.78	0.71	0.71	0.70	0.69	0.67	0.66
0.04		1.83	1.10	0.94	0.91	0.93	0.93	0.92	0.91	0.90	0.88	0.87
0.06		1.69	1.20	1.03	1.07	1.09	1.09	1.08	1.07	1.07	1.07	1.06
0.08		1.68	1.40	1.31	1.30	1.30	1.30	1.28	1.26	1.22	1.22	1.22
0.10		2.04	1.57	1.56	1.54	1.52	1.49	1.45	1.44	1.42	1.42	1.42
0.12		2.04	1.97	1.93	1.89	1.84	1.77	1.70	1.63	1.62	1.61	1.61
0.14		2.17	2.15	2.09	2.02	1.96	1.90	1.85	1.81	1.80	1.80	1.80
0.16		2.34	2.27	2.21	2.15	2.11	2.09	2.05	2.01	1.99	1.99	1.99
0.18		2.48	2.48	2.49	2.45	2.39	2.33	2.27	2.19	2.18	2.18	2.17
0.20		2.61	2.62	2.62	2.59	2.56	2.51	2.45	2.40	2.40	2.39	2.38
0.22		3.04	2.92	2.83	2.82	2.79	2.74	2.69	2.69	2.59	2.58	2.57
0.24		3.35	3.08	2.94	2.88	2.82	2.80	2.80	2.79	2.78	2.77	2.76
0.26		3.39	3.20	3.18	3.14	3.06	2.92	2.92	2.93	2.92	2.91	2.90
0.28		3.41	3.32	3.28	3.19	3.02	2.96	2.94	2.93	2.91	2.90	2.88
0.30		3.51	3.48	3.32	3.14	2.99	2.95	2.94	2.92	2.91	2.89	2.87

		3.14										
		($\cdot 10^7 \text{ N}\cdot\text{m}$);										
$m \backslash T$	T	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
0.02		2.22	1.10	0.95	0.79	0.73	0.73	0.72	0.71	0.70	0.67	0.67
0.04		1.92	1.15	0.96	0.90	0.92	0.92	0.91	0.90	0.88	0.87	0.85
0.06		1.72	1.21	1.03	1.06	1.07	1.08	1.07	1.08	1.08	1.07	1.05
0.08		1.85	1.56	1.30	1.29	1.28	1.28	1.26	1.24	1.22	1.21	1.21
0.10		1.99	1.58	1.56	1.58	1.55	1.55	1.44	1.44	1.43	1.42	1.42
0.12		1.96	1.97	1.93	1.87	1.81	1.81	1.69	1.64	1.61	1.61	1.61
0.14		2.03	1.97	1.98	1.94	1.87	1.87	1.82	1.81	1.81	1.80	1.80
0.16		2.31	2.20	2.20	2.19	2.15	2.15	2.04	2.00	2.00	1.99	1.99
0.18		2.50	2.51	2.48	2.44	2.39	2.39	2.27	2.20	2.19	2.18	2.18
0.20		2.67	2.65	2.60	2.63	2.59	2.50	2.45	2.39	2.37	2.37	2.37
0.22		3.21	2.99	2.78	2.70	2.69	2.67	2.63	2.58	2.57	2.57	2.56
0.24		3.12	3.08	3.11	3.06	2.95	2.83	2.79	2.78	2.77	2.76	2.75
0.26		2.99	2.98	2.97	2.96	2.96	2.95	2.93	2.92	2.91	2.90	2.88
0.28		3.08	3.09	3.08	3.07	3.05	3.04	3.02	3.01	2.99	2.98	2.96
0.30		3.08	3.09	3.08	3.07	3.05	3.04	3.02	3.01	2.99	2.98	2.96



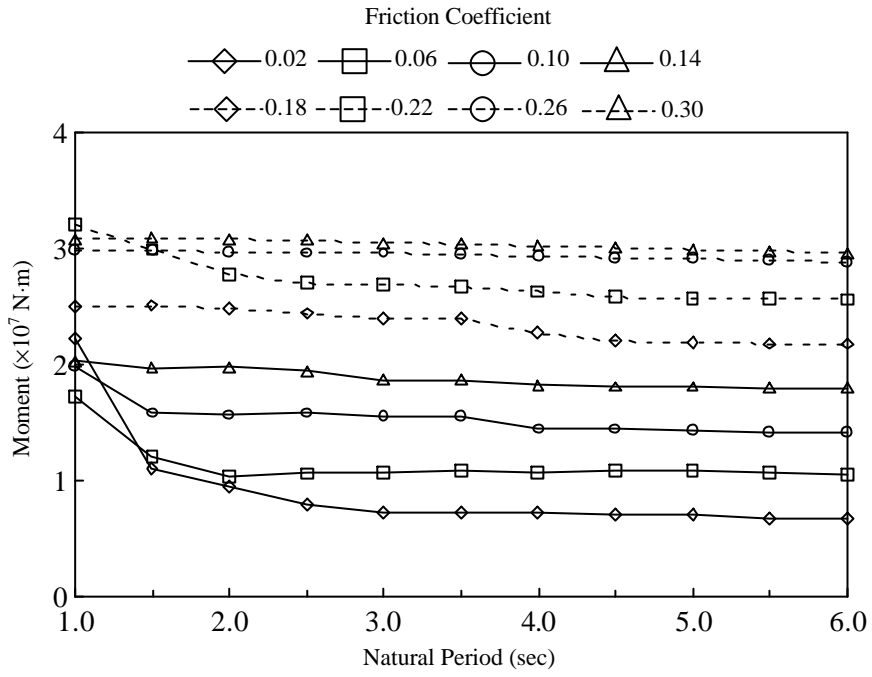
3.19

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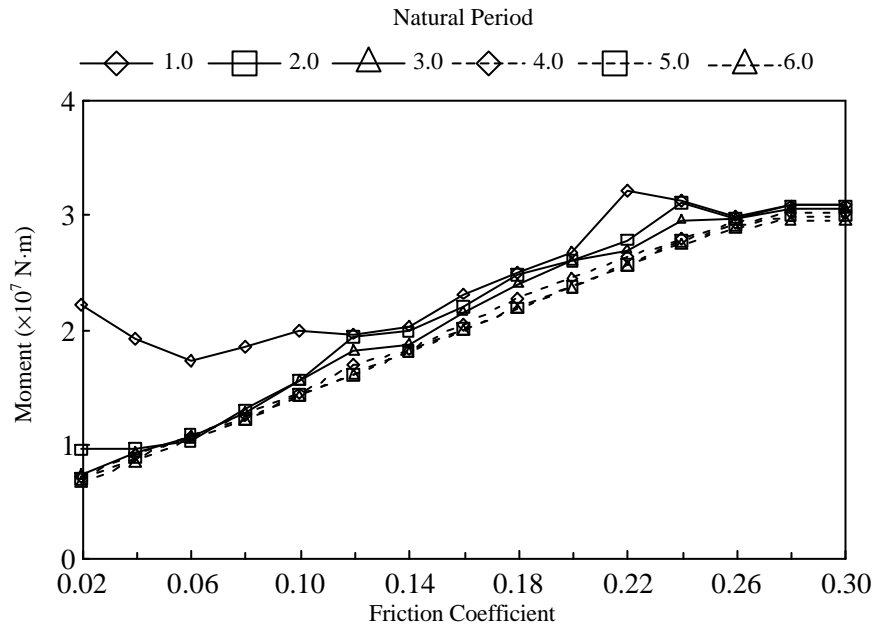
3.20

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3.21

;



3.22

;

3.2.2.4 EDF(Electricité De France) System

EDF System

EDF System

3.15 ~ 3.20

가 가 EDF System

LRB System

EDF System

P-F System R-FBI System

가

3.21 ~ 3.24

가 가

가

P-F System R-FBI System

가

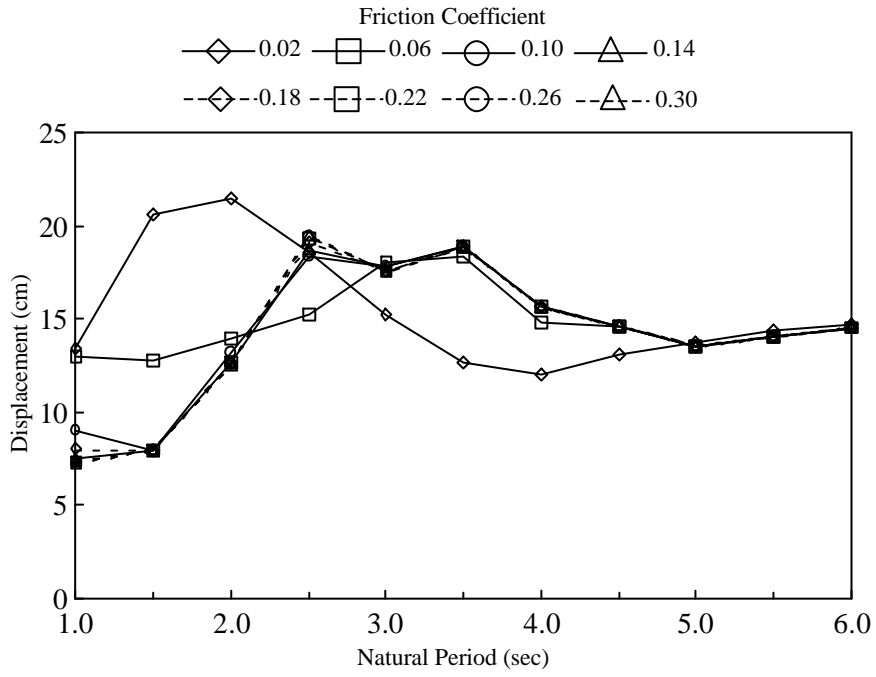
가

		3.15 (cm);										
<i>m</i> \ T	T	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
0.02		13.41	20.58	21.44	18.54	15.25	12.64	12.02	13.03	13.75	14.31	14.69
0.04		16.77	16.15	11.09	13.41	18.25	18.27	14.59	14.14	13.38	14.03	14.48
0.06		12.96	12.70	13.92	15.25	18.02	18.33	14.82	14.54	13.51	14.01	14.50
0.08		10.90	8.77	14.31	18.71	17.87	18.65	15.38	14.60	13.51	14.01	14.50
0.10		9.01	7.90	13.16	18.35	17.80	18.86	15.62	14.60	13.51	14.01	14.50
0.12		8.09	7.95	12.82	18.53	17.75	18.88	15.62	14.60	13.51	14.01	14.50
0.14		7.52	7.90	12.66	18.69	17.76	18.84	15.62	14.60	13.51	14.01	14.50
0.16		7.54	7.88	12.61	18.86	17.67	18.83	15.62	14.60	13.51	14.01	14.50
0.18		7.99	7.89	12.63	19.05	17.55	18.83	15.62	14.60	13.51	14.01	14.50
0.20		7.56	7.92	12.63	19.20	17.51	18.83	15.62	14.60	13.51	14.01	14.50
0.22		7.32	7.96	12.59	19.33	17.51	18.83	15.62	14.60	13.51	14.01	14.50
0.24		7.25	7.94	12.55	19.46	17.51	18.83	15.62	14.60	13.51	14.01	14.50
0.26		7.24	7.94	12.52	19.46	17.51	18.83	15.62	14.60	13.51	14.01	14.50
0.28		7.23	7.97	12.51	19.43	17.51	18.83	15.62	14.60	13.51	14.01	14.50
0.30		7.22	8.00	12.49	19.42	17.51	18.83	15.62	14.60	13.51	14.01	14.50

		3.16 (cm);										
<i>m</i> \ T	T	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
0.02		14.05	21.32	21.19	17.99	14.19	11.98	12.29	13.20	13.65	14.19	14.54
0.04		17.24	14.75	10.58	14.58	13.46	18.07	14.65	13.41	13.65	14.20	14.54
0.06		13.92	12.43	14.05	15.95	19.85	17.11	14.35	13.22	13.65	14.20	14.54
0.08		11.19	8.42	15.80	17.47	19.39	16.76	14.35	13.22	13.65	14.20	14.54
0.10		9.52	7.86	14.39	19.69	19.25	16.70	14.35	13.22	13.65	14.20	14.54
0.12		8.61	8.49	14.09	19.43	19.20	16.70	14.35	13.22	13.65	14.20	14.54
0.14		8.07	8.43	14.09	19.35	19.19	16.70	14.35	13.22	13.65	14.20	14.54
0.16		8.02	8.37	14.09	19.36	19.19	16.70	14.35	13.22	13.65	14.20	14.54
0.18		8.58	8.36	14.09	19.36	19.19	16.70	14.35	13.22	13.65	14.20	14.54
0.20		8.35	8.37	14.09	19.36	19.19	16.70	14.35	13.22	13.65	14.20	14.54
0.22		8.10	8.37	14.09	19.36	19.19	16.70	14.35	13.22	13.65	14.20	14.54
0.24		7.96	8.37	14.09	19.36	19.19	16.70	14.35	13.22	13.65	14.20	14.54
0.26		7.94	8.37	14.09	19.36	19.19	16.70	14.35	13.22	13.65	14.20	14.54
0.28		7.96	8.37	14.09	19.36	19.19	16.70	14.35	13.22	13.65	14.20	14.54
0.30		7.98	8.37	14.09	19.36	19.19	16.70	14.35	13.22	13.65	14.20	14.54

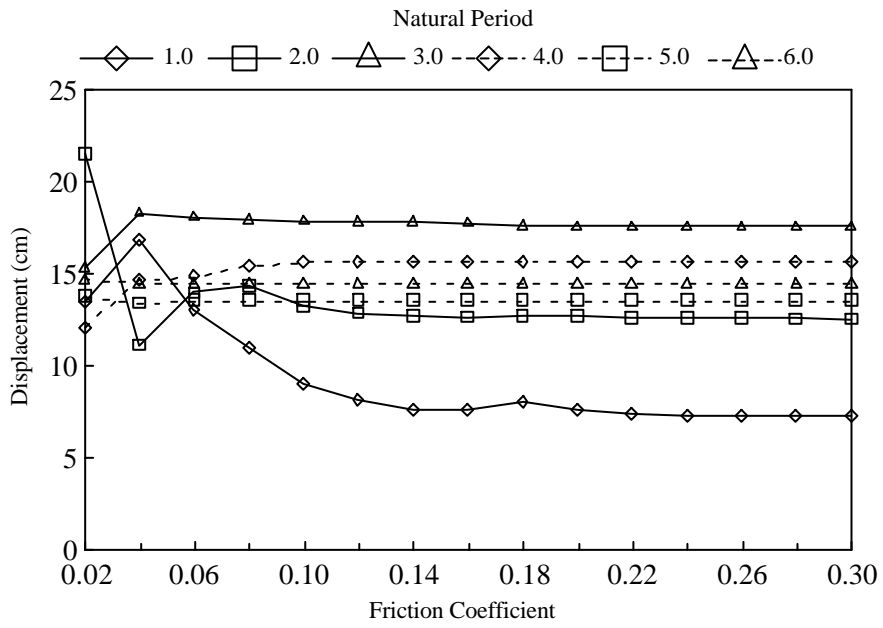
		3.17										
		(cm);										
<i>m</i> \ T	T	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
0.02		13.41	20.58	21.44	18.54	15.25	12.64	12.02	13.03	13.75	14.31	14.69
0.04		16.76	16.14	11.08	13.40	18.24	18.26	14.59	14.14	13.38	14.03	14.48
0.06		12.95	12.68	13.90	15.23	18.00	18.32	14.81	14.54	13.51	14.01	14.50
0.08		10.88	8.74	14.29	18.69	17.85	18.64	15.37	14.60	13.51	14.01	14.50
0.10		8.98	7.87	13.13	18.33	17.79	18.85	15.61	14.60	13.51	14.01	14.50
0.12		8.05	7.92	12.79	18.51	17.74	18.87	15.61	14.60	13.51	14.01	14.50
0.14		7.47	7.86	12.63	18.66	17.66	18.83	15.61	14.60	13.51	14.01	14.50
0.16		7.49	7.85	12.58	18.84	17.54	18.82	15.61	14.60	13.51	14.01	14.50
0.18		7.93	7.86	12.60	19.03	17.50	18.82	15.61	14.60	13.51	14.01	14.50
0.20		7.50	7.88	12.60	19.17	17.50	18.82	15.61	14.60	13.51	14.01	14.50
0.22		7.25	7.92	12.56	19.30	17.50	18.82	15.61	14.60	13.51	14.01	14.50
0.24		7.18	7.91	12.52	19.43	17.50	18.82	15.61	14.60	13.51	14.01	14.50
0.26		7.17	7.91	12.49	19.43	17.50	18.82	15.61	14.60	13.51	14.01	14.50
0.28		7.16	7.93	12.47	19.41	17.50	18.82	15.61	14.60	13.51	14.01	14.50
0.30		7.15	7.97	12.46	19.39	17.50	18.82	15.61	14.60	13.51	14.01	14.50

		3.18										
		(cm);										
<i>m</i> \ T	T	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
0.02		14.05	21.32	21.19	17.99	14.19	11.97	12.29	13.20	13.65	14.19	14.54
0.04		17.24	14.75	10.57	14.58	13.45	18.07	14.65	13.41	13.65	14.20	14.54
0.06		13.92	12.43	14.05	15.94	19.85	17.10	14.35	13.22	13.65	14.20	14.54
0.08		11.19	8.41	15.80	17.47	19.39	16.75	14.35	13.22	13.65	14.20	14.54
0.10		9.51	7.85	14.39	19.68	19.24	16.70	14.35	13.22	13.65	14.20	14.54
0.12		8.60	8.48	14.08	19.42	19.19	16.70	14.35	13.22	13.65	14.20	14.54
0.14		8.06	8.42	14.08	19.35	19.18	16.70	14.35	13.22	13.65	14.20	14.54
0.16		8.01	8.37	14.08	19.35	19.18	16.70	14.35	13.22	13.65	14.20	14.54
0.18		8.57	8.36	14.08	19.35	19.18	16.70	14.35	13.22	13.65	14.20	14.54
0.20		8.34	8.36	14.08	19.35	19.18	16.70	14.35	13.22	13.65	14.20	14.54
0.22		8.10	8.36	14.08	19.35	19.18	16.70	14.35	13.22	13.65	14.20	14.54
0.24		7.94	8.36	14.08	19.35	19.18	16.70	14.35	13.22	13.65	14.20	14.54
0.26		7.92	8.36	14.08	19.35	19.18	16.70	14.35	13.22	13.65	14.20	14.54
0.28		7.94	8.36	14.08	19.35	19.18	16.70	14.35	13.22	13.65	14.20	14.54
0.30		7.96	8.36	14.08	19.35	19.18	16.70	14.35	13.22	13.65	14.20	14.54



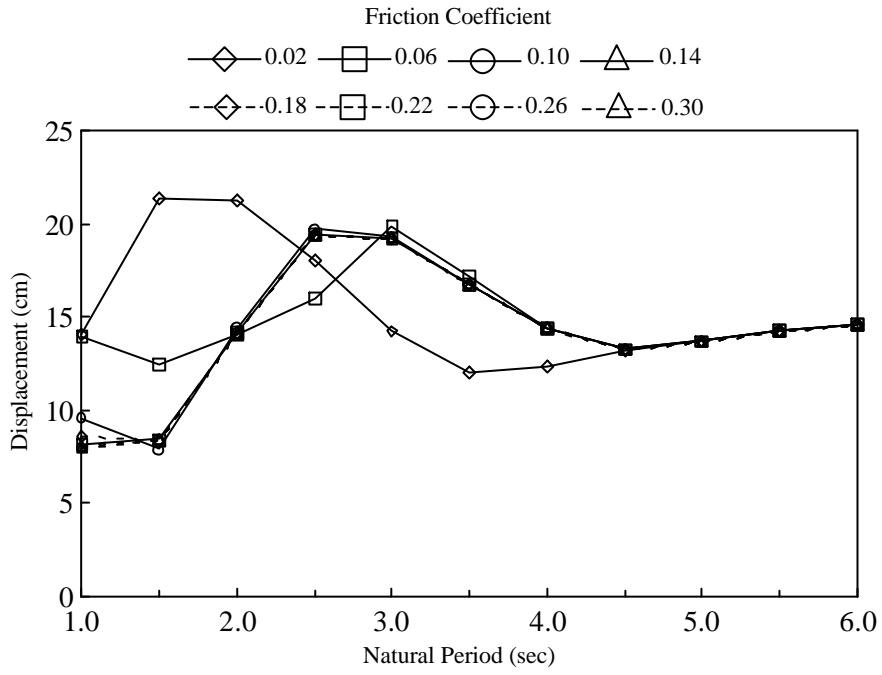
3.23

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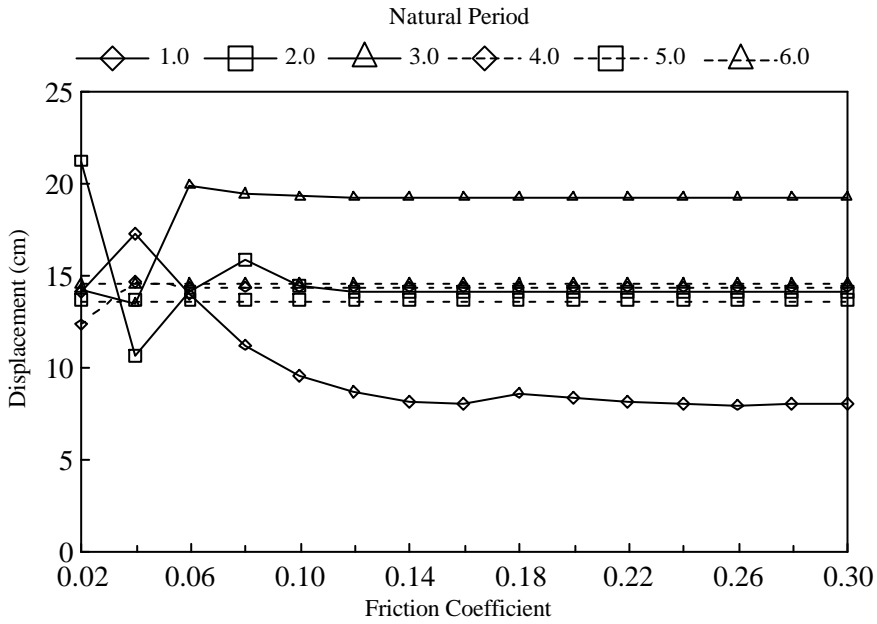


3.24

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3.25 ;



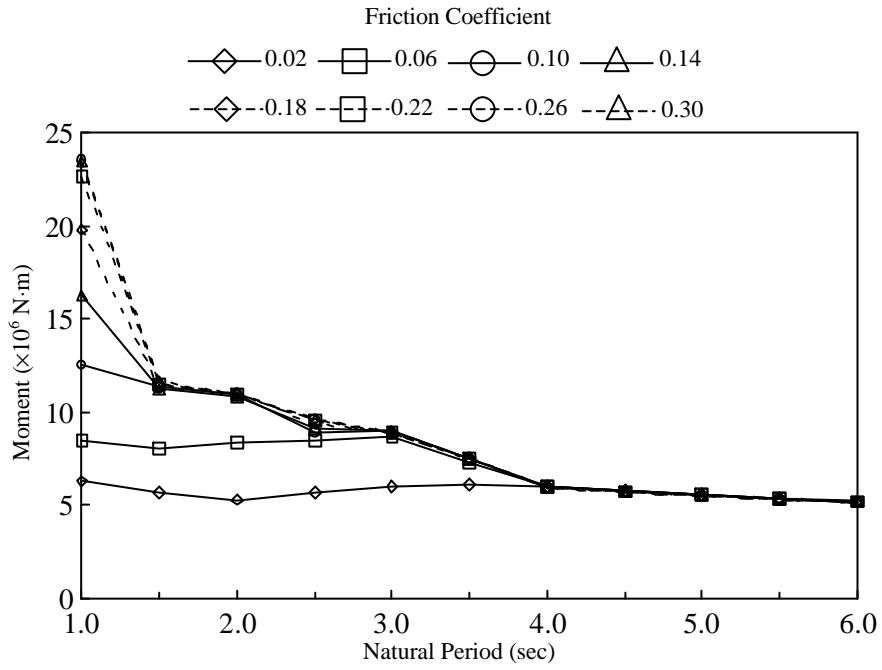
3.26 ;

		3.21										
		($\cdot 10^6$ N);										
$m \backslash T$		1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
0.02		1.21	1.08	1.03	1.12	1.16	1.17	1.17	1.13	1.10	1.07	1.05
0.04		1.16	1.13	1.09	1.15	1.20	1.19	1.16	1.13	1.10	1.07	1.05
0.06		1.35	1.27	1.34	1.35	1.40	1.21	1.16	1.13	1.10	1.07	1.05
0.08		1.60	1.19	1.42	1.38	1.44	1.22	1.16	1.13	1.10	1.07	1.05
0.10		1.88	1.66	1.61	1.38	1.44	1.23	1.16	1.13	1.10	1.07	1.05
0.12		2.11	1.63	1.60	1.39	1.44	1.24	1.16	1.13	1.10	1.07	1.05
0.14		2.39	1.63	1.59	1.40	1.44	1.23	1.16	1.13	1.10	1.07	1.05
0.16		2.65	1.62	1.60	1.41	1.43	1.23	1.16	1.13	1.10	1.07	1.05
0.18		2.86	1.62	1.61	1.43	1.43	1.23	1.16	1.13	1.10	1.07	1.05
0.20		3.08	1.62	1.61	1.43	1.42	1.23	1.16	1.13	1.10	1.07	1.05
0.22		3.19	1.63	1.61	1.43	1.42	1.23	1.16	1.13	1.10	1.07	1.05
0.24		3.26	1.62	1.61	1.43	1.42	1.23	1.16	1.13	1.10	1.07	1.05
0.26		3.25	1.61	1.61	1.43	1.42	1.23	1.16	1.13	1.10	1.07	1.05
0.28		3.25	1.60	1.61	1.43	1.42	1.23	1.16	1.13	1.10	1.07	1.05
0.30		3.24	1.61	1.61	1.43	1.42	1.23	1.16	1.13	1.10	1.07	1.05

		3.22										
		($\cdot 10^6$ N);										
$m \backslash T$		1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
0.02		1.22	1.09	1.08	1.14	1.17	1.17	1.12	1.12	1.09	1.06	1.04
0.04		1.12	1.10	1.12	1.15	1.20	1.19	1.15	1.12	1.09	1.06	1.04
0.06		1.36	1.33	1.36	1.39	1.40	1.18	1.15	1.12	1.09	1.06	1.04
0.08		1.61	1.42	1.43	1.46	1.51	1.18	1.15	1.12	1.09	1.06	1.04
0.10		1.86	1.65	1.68	1.47	1.50	1.18	1.15	1.12	1.09	1.06	1.04
0.12		2.13	1.67	1.73	1.47	1.50	1.18	1.15	1.12	1.09	1.06	1.04
0.14		2.40	1.67	1.73	1.47	1.50	1.18	1.15	1.12	1.09	1.06	1.04
0.16		2.66	1.66	1.73	1.47	1.50	1.18	1.15	1.12	1.09	1.06	1.04
0.18		2.88	1.66	1.73	1.47	1.50	1.18	1.15	1.12	1.09	1.06	1.04
0.20		3.10	1.66	1.73	1.47	1.50	1.18	1.15	1.12	1.09	1.06	1.04
0.22		3.30	1.66	1.73	1.47	1.50	1.18	1.15	1.12	1.09	1.06	1.04
0.24		3.37	1.66	1.73	1.47	1.50	1.18	1.15	1.12	1.09	1.06	1.04
0.26		3.54	1.66	1.73	1.47	1.50	1.18	1.15	1.12	1.09	1.06	1.04
0.28		3.54	1.66	1.73	1.47	1.50	1.18	1.15	1.12	1.09	1.06	1.04
0.30		3.55	1.66	1.73	1.47	1.50	1.18	1.15	1.12	1.09	1.06	1.04

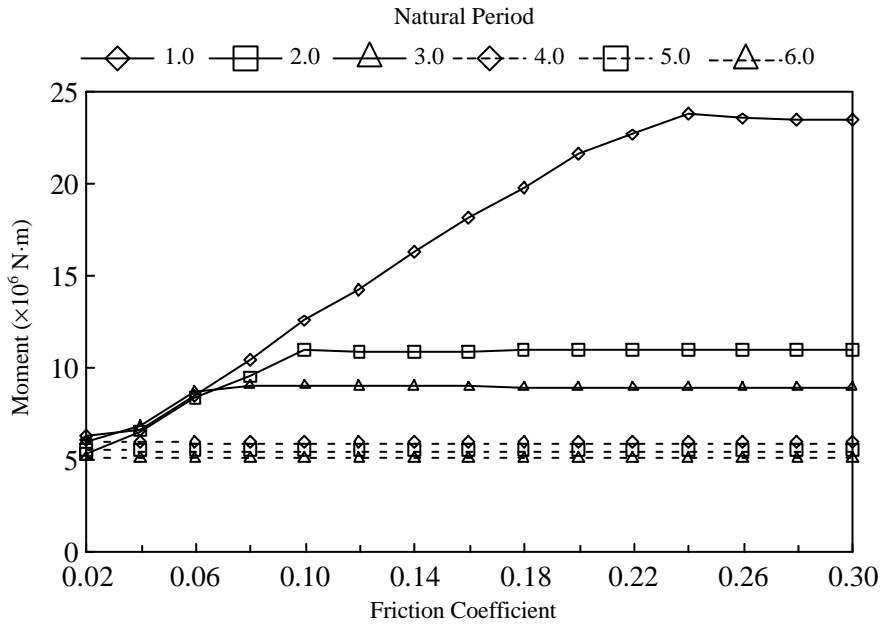
		3.23										
		($\cdot 10^6 \text{ N}\cdot\text{m}$);										
$m \backslash T$		1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
0.02		6.25	5.64	5.27	5.64	5.96	6.05	5.99	5.75	5.52	5.33	5.17
0.04		6.62	6.79	6.52	6.78	6.76	6.75	5.96	5.72	5.50	5.32	5.16
0.06		8.42	8.00	8.35	8.41	8.69	7.27	5.93	5.71	5.50	5.32	5.16
0.08		10.37	9.51	9.47	8.81	8.99	7.39	5.93	5.71	5.50	5.32	5.16
0.10		12.51	11.30	10.94	8.89	8.97	7.46	5.93	5.71	5.50	5.32	5.16
0.12		14.22	11.23	10.82	9.02	8.95	7.47	5.93	5.71	5.50	5.32	5.16
0.14		16.25	11.21	10.80	9.13	8.95	7.47	5.93	5.71	5.50	5.32	5.16
0.16		18.12	11.25	10.85	9.24	8.92	7.47	5.93	5.71	5.50	5.32	5.16
0.18		19.77	11.31	10.92	9.36	8.88	7.47	5.93	5.71	5.50	5.32	5.16
0.20		21.55	11.38	10.95	9.45	8.86	7.47	5.93	5.71	5.50	5.32	5.16
0.22		22.61	11.45	10.94	9.53	8.86	7.47	5.93	5.71	5.50	5.32	5.16
0.24		23.77	11.46	10.93	9.60	8.86	7.47	5.93	5.71	5.50	5.32	5.16
0.26		23.49	11.48	10.93	9.61	8.86	7.47	5.93	5.71	5.50	5.32	5.16
0.28		23.45	11.54	10.93	9.60	8.86	7.47	5.93	5.71	5.50	5.32	5.16
0.30		23.41	11.61	10.93	9.60	8.86	7.47	5.93	5.71	5.50	5.32	5.16

		3.24										
		($\cdot 10^6 \text{ N}\cdot\text{m}$);										
$m \backslash T$		1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
0.02		6.29	5.76	5.42	5.77	5.99	6.01	5.92	5.67	5.45	5.27	5.12
0.04		6.56	6.56	6.57	6.81	6.78	6.75	5.90	5.66	5.45	5.27	5.12
0.06		8.50	8.31	8.49	8.56	8.71	6.79	5.89	5.66	5.45	5.27	5.12
0.08		10.39	9.49	9.56	9.46	9.47	6.70	5.89	5.66	5.45	5.27	5.12
0.10		12.38	11.21	11.45	9.51	9.43	6.70	5.89	5.66	5.45	5.27	5.12
0.12		14.40	12.05	11.81	9.52	9.42	6.70	5.89	5.66	5.45	5.27	5.12
0.14		16.26	12.06	11.82	9.52	9.42	6.70	5.89	5.66	5.45	5.27	5.12
0.16		18.24	12.01	11.82	9.52	9.42	6.70	5.89	5.66	5.45	5.27	5.12
0.18		19.84	11.99	11.82	9.52	9.42	6.70	5.89	5.66	5.45	5.27	5.12
0.20		20.56	11.99	11.82	9.52	9.42	6.70	5.89	5.66	5.45	5.27	5.12
0.22		23.18	11.99	11.82	9.52	9.42	6.70	5.89	5.66	5.45	5.27	5.12
0.24		24.36	11.99	11.82	9.52	9.42	6.70	5.89	5.66	5.45	5.27	5.12
0.26		25.62	11.99	11.82	9.52	9.42	6.70	5.89	5.66	5.45	5.27	5.12
0.28		25.66	11.99	11.82	9.52	9.42	6.70	5.89	5.66	5.45	5.27	5.12
0.30		25.69	11.99	11.82	9.52	9.42	6.70	5.89	5.66	5.45	5.27	5.12



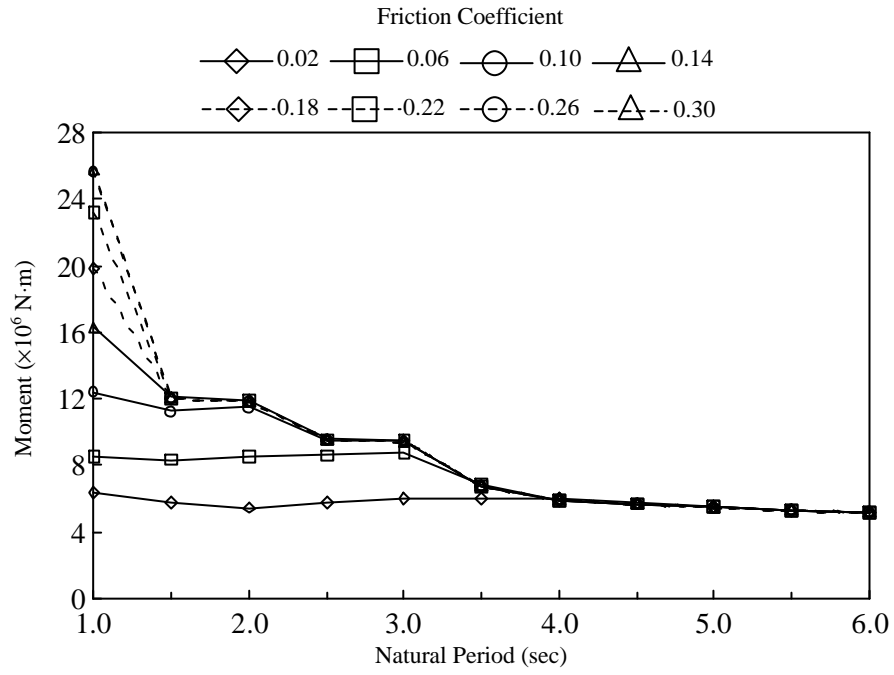
3.27

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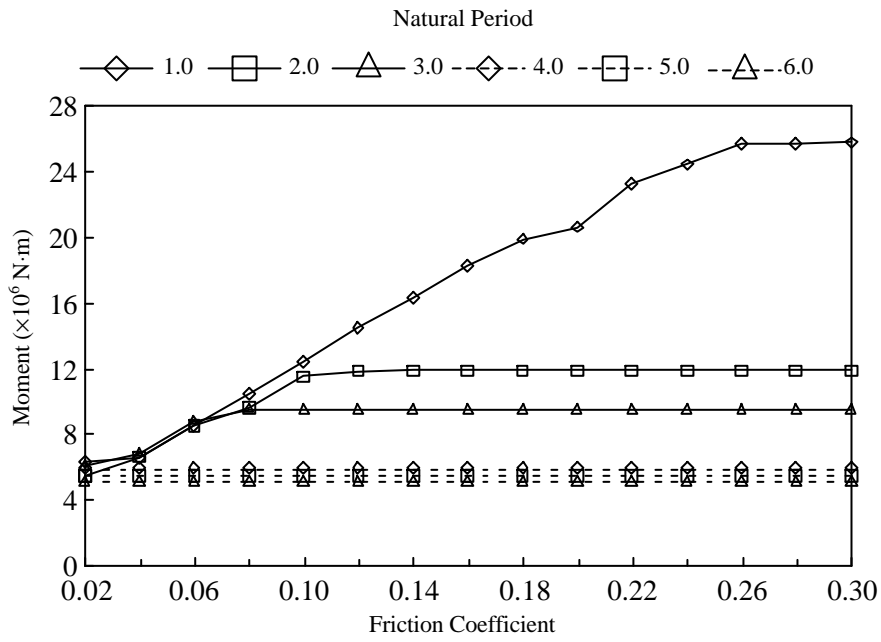
3.28

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3.29

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3.30

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3.2.3

3.25 1.0 ~ 6.0 , 0.02 ~ 0.30

El Centro

. P-F System, R-FBI System

가 , LRB System EDF System

P-F System, R-FBI System

가

가 . LRB System, EDF System

가 . 3.31

가

P-F System, R-FBI System

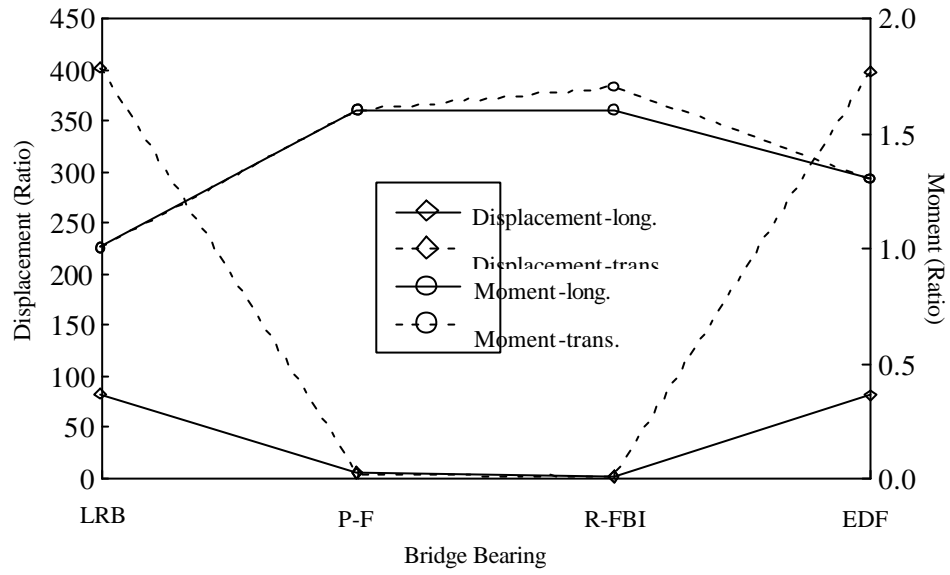
, LRB System, EDF System

3.25 ;

	(cm)		($\times 10^6$)	
			N·m)	
LRB System	7.39 (T=1.0 sec)	82.1	4.07 (T=6.0 sec)	1.0
P-F System	0.36 ($m=0.30$)	4.0	6.56 ($m=0.02$)	1.6
R-FBI System	0.09 (T \geq 3.0 sec, $m \geq 0.28$)	1.0	6.60 (T=6.0 sec, $m=0.02$)	1.6
EDF System	7.22 (T=1.0 sec, $m=0.30$)	80.2	5.16 (T=6.0 sec, $m \geq 0.04$)	1.3

3.26 ;

	(cm)		($\times 10^6$)	
			N·m)	
LRB System	8.02 (T=1.0 sec)	401.0	4.00 (T=6.0 sec)	1.0
P-F System	0.09 ($m=0.30$)	4.5	6.51 ($m=0.02$)	1.6
R-FBI System	0.02 (T \geq 1.0 sec, $m \geq 0.28$)	1.0	6.70 (T \geq 5.5 sec, $m=0.02$)	1.7
EDF System	7.94 (T=1.0 sec, $m=0.26$)	397.0	5.12 (T=6.0 sec, $m \geq 0.02$)	1.3



3.31

4

LRB(Laminated Rubber Bearing) System, P-F(Pure-Friction) System, R-FBI(Resilient-Friction Base Isolation) System, EDF(Electricitè De France) System 가 El Centro

,

(0.02 ~ 0.30) (1.0 ~ 6.0)

1. 가 가 가 () 가 .
2. R-FBI System 가 P-F System, EDF System, LRB System .
3. LRB System 가 EDF System, P-F System, R-FBI System .

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1994.3 – 1998.2
1998.3 – 2000.2

(B.S.)

(M.S.)

1. , (2000), “

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1. , , (1999), “ 가

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