BRIDGE DESIGN EXAMPLE FOR 2ND U.S. – JAPAN WORKSHOP ON PROTECTIVE SYSTEMS FOR BRIDGES

by

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1. INTRODUCTION

The project description is shown in Table 1. Design specifications are limited to performance criteria and they do not include minimum limits on design displacements. It was assumed that the design could be based on nonlinear dynamic analysis. For this purpose, the mathematical model used in the dynamic analysis was verified by comparison to shake table test results of a large scale bridge model. The earthquake input was represented by simulated motions compatible with the specified design spectra.

A detailed design was developed for the 0.4g, soil type 2 AASHTO spectrum. Furthermore, a design was developed for the Japanese Level 2, Ground Condition 2 bridge design spectrum, anchored at 0.4g peak ground acceleration. Both designs are based on the performance criterion of minimum isolation system displacement with pier force less than 40% of the supported weight.

2. EARTHQUAKE INPUT

Figure 1 shows the design spectra of AASHTO and Japanese bridge design code for soil type 2 (or G.C. 2) and PGA=0.4g. For comparison, Figure 1 includes the Japanese spectra for G.C. 1 (stiff soil) and G.C. 3 (very soft soil), also for PGA=0.4g.

Figures 2 and 3 show two simulated motions compatible with the AASHTO spectrum. These motions have PGA=0.4g, PGV=600 mm/sec and PGD=325 and 420 mm. The authors consider them representative of the design spectrum.

Figure 4 shows time histories of simulated motions used in Japan for bridge design. The spectra of the motions are shown in Figure 1. The motion for Level 2, Ground Condition 2 has been used for the analyses of the designed isolation system.

3. SEISMIC ISOLATION SYSTEM

The isolation system consists of sliding-bearings, rubber restoring force devices and fluid viscous dampers. This system has been recently tested at U. Buffalo and results are presented at the workshop (paper by Okamoto, Constantinou, Tsopelas, Fujii and Ozaki). The attached NCEER publication provides an overview of the research program. The layout of the isolation system is shown in Figures 5 and 6.

Each sliding bearing carries a load of 4000 kN. The sliding interface will consist of polished stainless steel and a woven composite with PTFE included in its matrix. The composite has approximately the frictional properties of PTFE but substantially more bearing capacity (rated at 275 MPa) and wear life. The frictional properties of the interface are shown in Figure 7. The bearing pressure will be 23 MPa, for which the coefficient of friction at large velocity of sliding is 0.10. Alternatively, glass filled Teflon at 15% by weight under bearing pressure of 13.8 MPa may be used. It can deliver a friction coefficient of 0.10.

The restoring force devices were shaped in a manner similar to the one used in the shake table testing at U. Buffalo (see attached NCEER publication and paper by Okamoto). The devices are designed to deliver linear stiffness of 1790 kN/m each up to displacements of ±100 mm for the AASHTO motion and ±200 mm for the Japanese motion. Beyond this limit, they exhibit large stiffness and act as displacement restrainers.

The fluid dampers represent standard equipment typically used in the U.S. in military applications. Over 13,000 of these devices are currently in service in the U.S. They employ fluidic control orifices and passive thermostats which allow operation over the temperature range of -40°to 70°C (see attached paper by Shinozuka, Constantinou and Ghanem). The fluid dampers are designed to have a damping constant equal to 1.37 kN sec/mm, displacement capacity of ±100 mm and rated load capacity of 450 kN for the AASHTO motion, and ±200 mm and 588 kN for the Japanese motion.

4. MATHEMATICAL MODEL OF BRIDGE

The mathematical model for nonlinear dynamic analysis is shown in Figure 8. It accounts for the nonlinear characteristics of the isolation and for the pier flexibility. It neglects higher mode effects of the pier, deck flexibility, pier rotation and soil flexibility.

Despite its simplicity, the model is capable of capturing well the response of the tested bridge model with similar dynamic characteristics. Figure 9 shows the tested bridge model (quarter length scale). In one testing configuration, the model had $T_{PIER} = 0.1$ secs, $T_{ISO} = 1.4$ secs, $\mu = 0.14$ and $\xi_{ISO} = 0$ or 0.47, thus very similar to the designed isolated bridge.

Test and simulation results with input being the Japanese Level 2, G.C. 2 (scaled at 75%) motion are shown in Figures 10 and 11.

5. RESPONSE OF DESIGNED ISOLATED BRIDGE

The peak response of the isolated bridge for the AASHTO motion is presented in Table 2. Analyses were performed for coefficient of friction equal to 0.10 and 0.12. The latter case is used to obtain upper bounds on the design forces while the former case is used to obtain upper bounds on displacements.

Furthermore, Table 2 presents the peak response for the Japanese Level 2, Ground Condition 2 motion. From these results the design values were determined and presented in Table 3. Evidently, the design satisfies the limit of 0.4 times the carried weight of shear in the pier while displacements are, respectively 71 mm and 175 mm for the AASHTO and Japanese motions.

Details of the designed sliding bearings, rubber restoring force devices and fluid dampers for the AASHTO motions are shown in Figures 12 to 14. The displacement capacity of the system (for AASHTO motion) is 40% more than the calculated response. This was thought to be necessary for accommodating bidirectional motions, unanticipated stronger motions and thermal movements (estimated at ±5 mm for ±25°C temperature changes).
Detail of the design for the Japanese motion are not presented. However, the results of Table 3 provide the necessary information for the detailing of the isolation elements.

TABLE 1
PROPOSED BRIDGE DESIGN EXAMPLES
SECOND US-JAPAN WORKSHOP ON PROTECTIVE SYSTEMS FOR BRIDGES

Bridge Geometry:	Single span segment of a long bridge Span length = 40 m Clear height at support = 10 m Width of superstructure = 14 m Depth of superstructure = 2 m Weight of superstructure = 200 kN/m
Bridge Materials:	Reinforced concrete
Bridge Substructure:	Could be single column or multiple column
Foundation:	Spread footing on moderate soil U.S. Soil Type 2 (a stiff clay or deep cohesionless conditions greater than 60 m in depth)
Peak Ground Acceleration:	0.4 g
Spectral Shape:	2 design spectra, one U.S. the other Japanese, anchored to the above peak ground acceleration
Isolation Performance Criteria:	2 designs are required for each of the above 2 spectra to provide: (a) minimum forces in the substructure OR (b) minimum displacements in the superstructure provided the force in the substructure does not exceed 40% of the supported weight

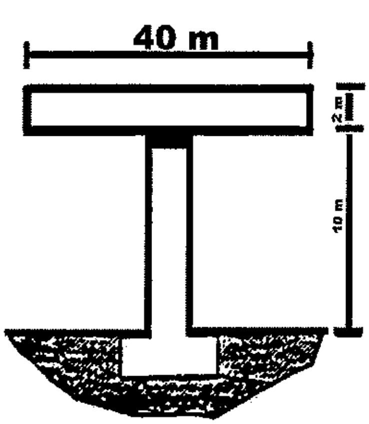
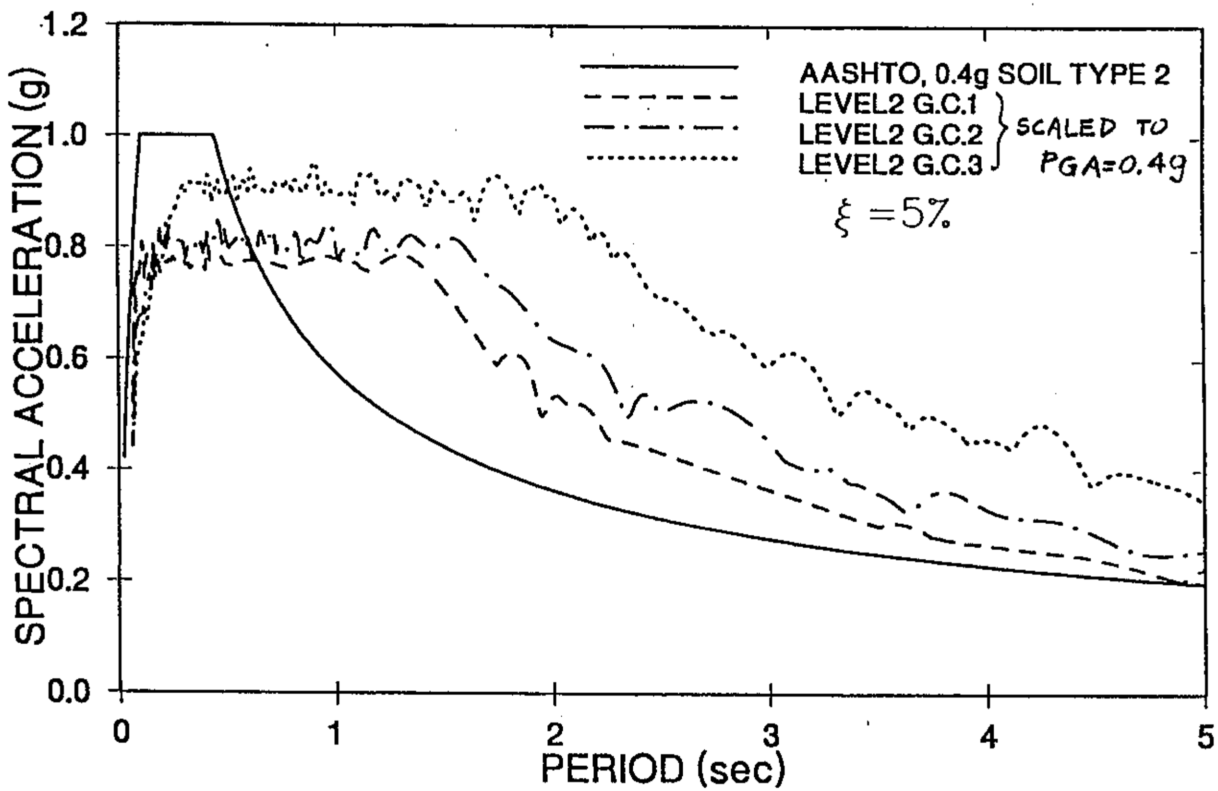


Table 2 : Peak Response of Isolated Bridge

EXCITATION		BEARING DISPL. (mm)		ISOLATION SYSTEM FORCE / WEIGHT		PIER TOP ACCEL. (g)		PIER SHEAR / WEIGHT		DAMPER FORCE (EACH kN)	
	DAMPERS	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES
	FRICTION										
AASHTO #1	0.10	109	71	0.148	0.177	0.76	0.77	0.229	0.266	0	423
	0.12	80	52	0.156	0.195	0.89	0.85	0.263	0.302	0	433
AASHTO #2	0.10	88	64	0.138	0.172	0.84	0.86	0.268	0.267	0	414
	0.12	87	64	0.160	0.190	0.94	0.84	0.307	0.295	0	412
JAPANESE LEVEL 2 G.C.2 (0.4 g)	0.10	242	175	0.208	0.258	0.91	0.84	0.267	0.324	0	564
	0.12	233	145	0.223	0.257	1.13	0.93	0.306	0.324	0	523

Table 3 : Design Values: Value in Parenthesis is Capacity of Designed System

SPECTRUM	BEARING DISPL. (mm)	ISOLATION SYSTEM FORCE / WEIGHT	PIER SHEAR / WEIGHT	DAMPER FORCE (kN)
AASHTO 0.4 g, S2	71 (100)	0.195	0.302	433 (670)
JAPANESE LEVEL 2 G.C.2	175 (200)	0.258	0.324	564 (890)



1.2
1.0
0.8
0.6
0.4
0.2
0.0
SPECTRAL ACCELERATION (g)
0
1
2
3
4
5
PERIOD (sec)
AASHTO, 0.4g SOIL TYPE 2
LEVEL2 G.C.1
LEVEL2 G.C.2
LEVEL2 G.C.3
SCALED TO PGA=0.4g
ξ =5%

FIGURE 1

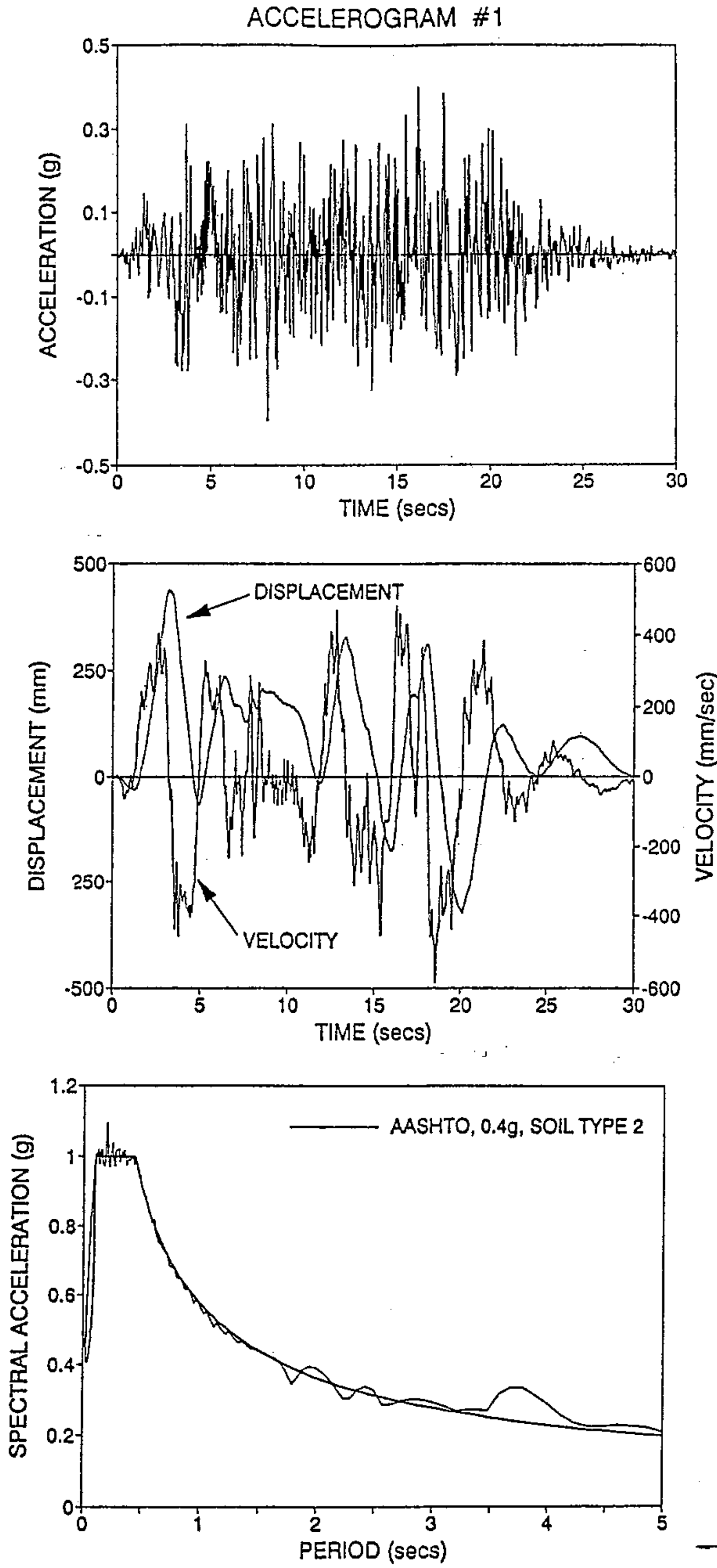

ACCELEROGRAM #1
ACCELERATION (g)
TIME (secs)
DISPLACEMENT
VELOCITY
DISPLACEMENT (mm)
VELOCITY (mm/sec)
TIME (secs)
AASHTO, 0.4g, SOIL TYPE 2
SPECTRAL ACCELERATION (g)
PERIOD (secs)

FIGURE 2

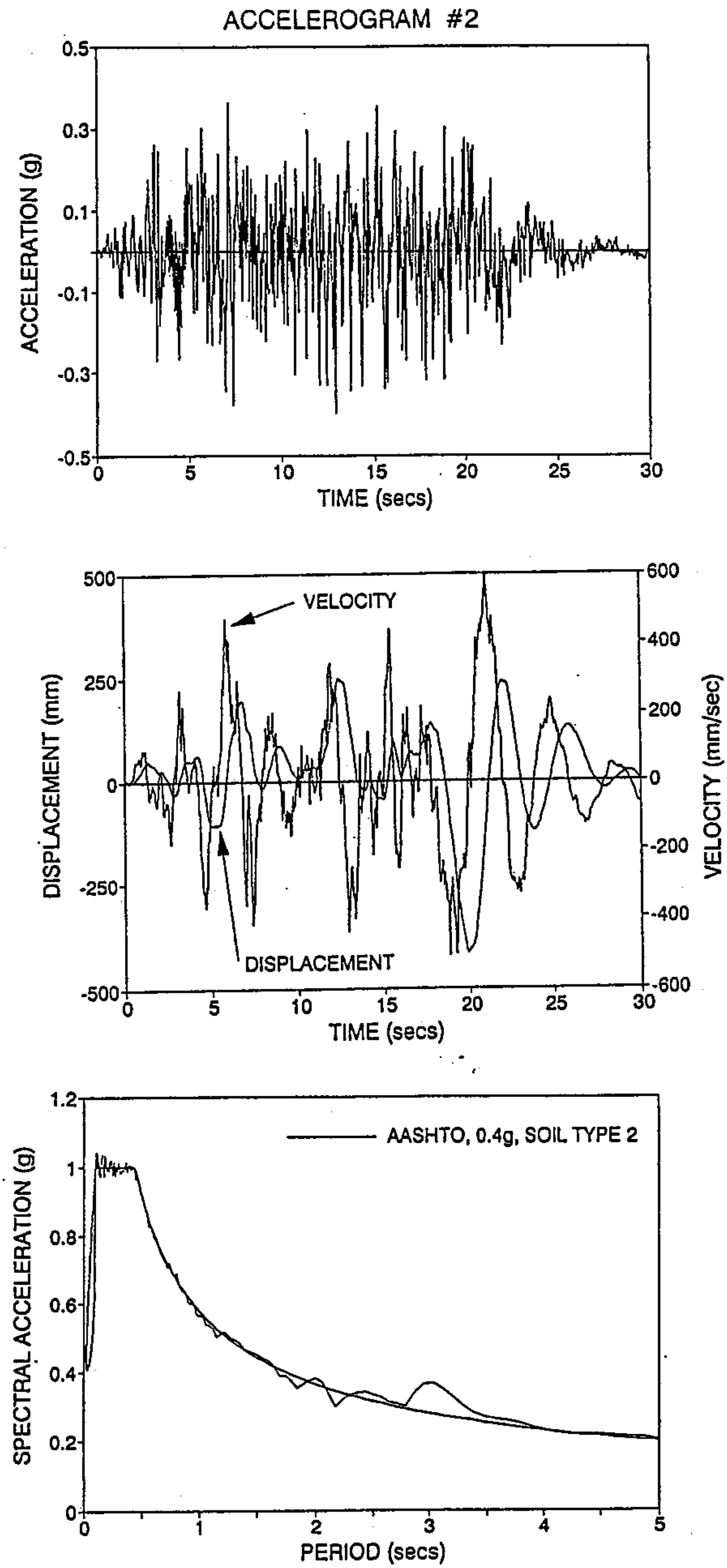

ACCELEROGRAM #2
ACCELERATION (g)
TIME (secs)
VELOCITY
DISPLACEMENT
DISPLACEMENT (mm)
VELOCITY (mm/sec)
TIME (secs)
AASHTO, 0.4g, SOIL TYPE 2
SPECTRAL ACCELERATION (g)
PERIOD (secs)

FIGURE 3

JAPANESE BRIDGE DESIGN MOTIONS

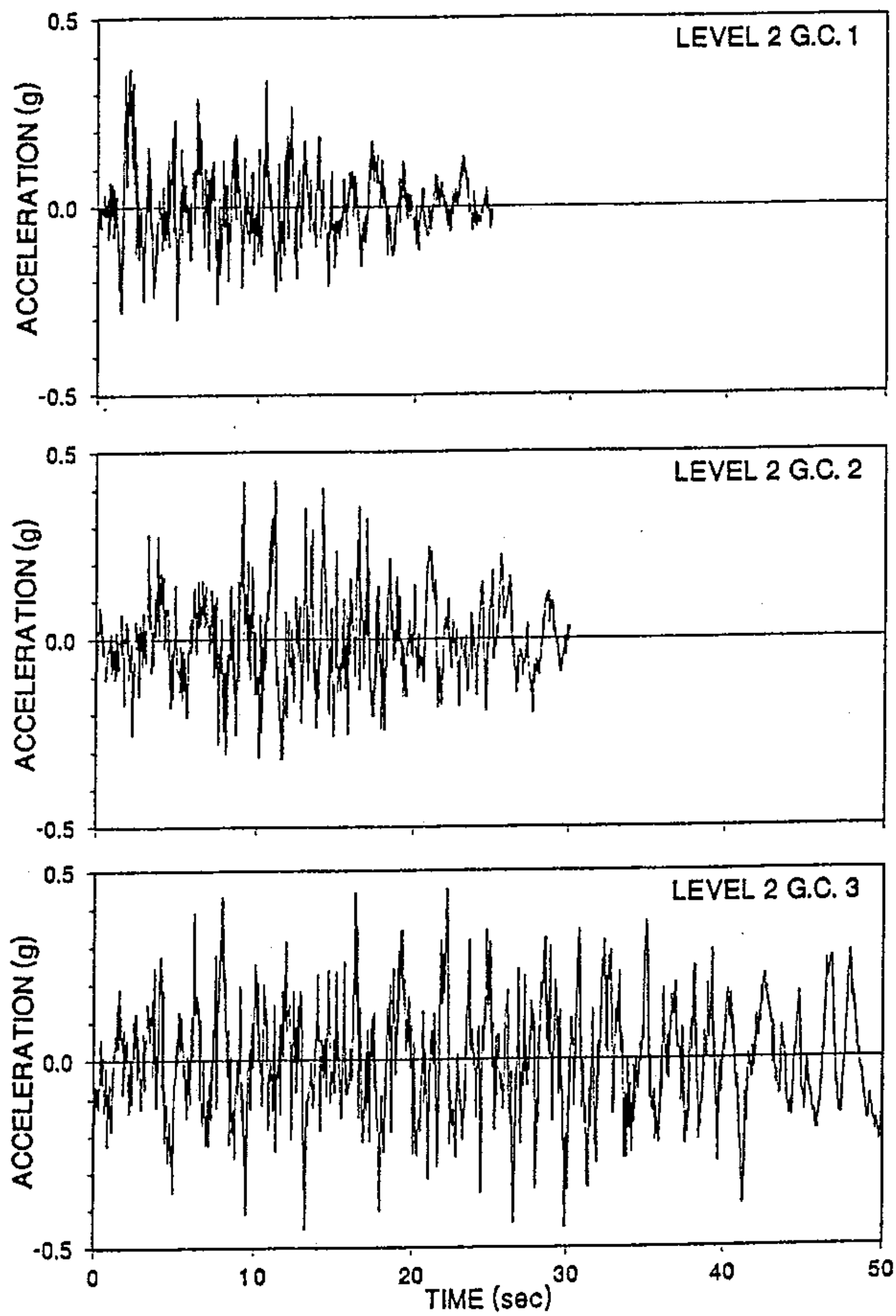


FIGURE 4

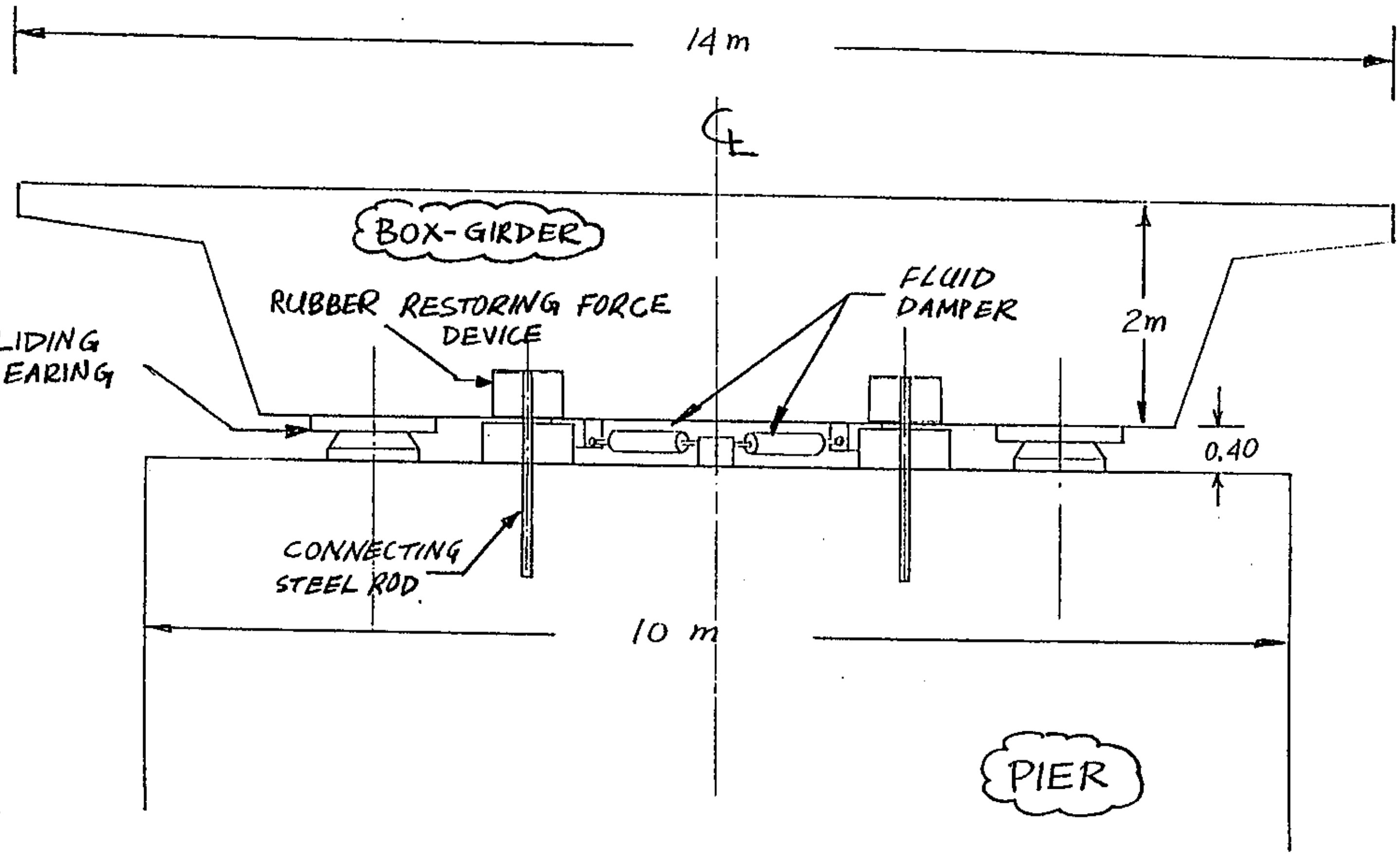

14 m
BOX-GIRDER
RUBBER RESTORING FORCE DEVICE
SLIDING BEARING
FLUID DAMPER
2m
0,40
CONNECTING STEEL ROD
10 m
PIER

FIGURE 5

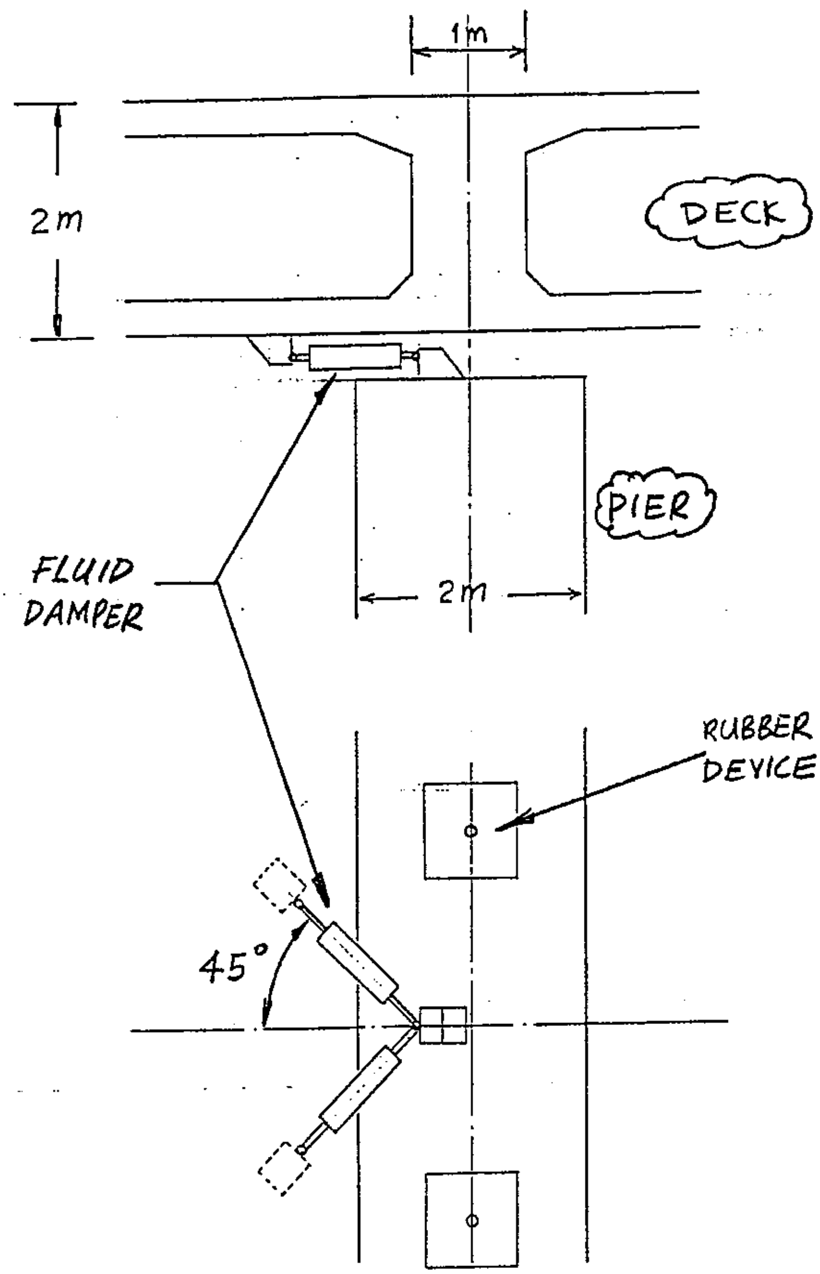
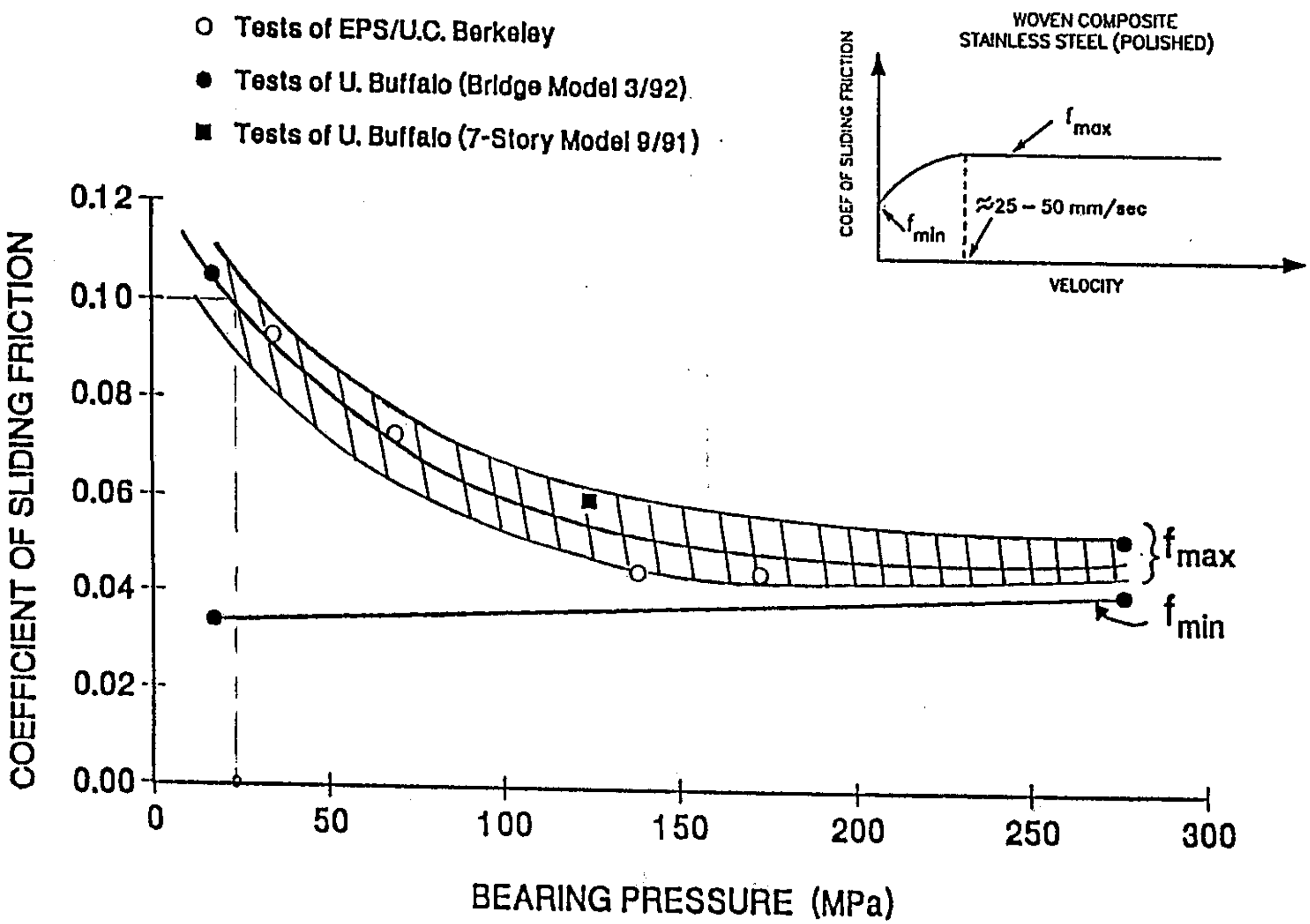
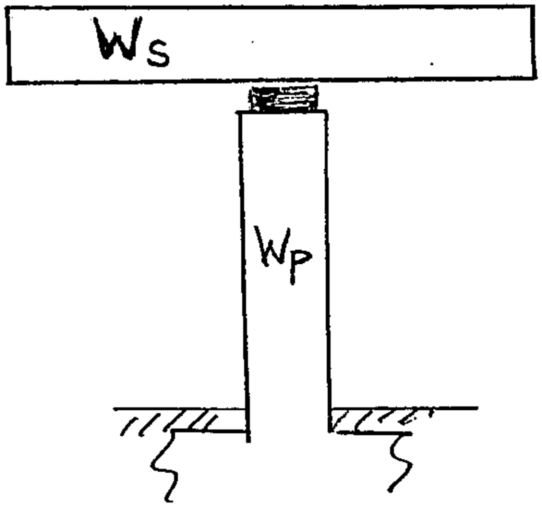


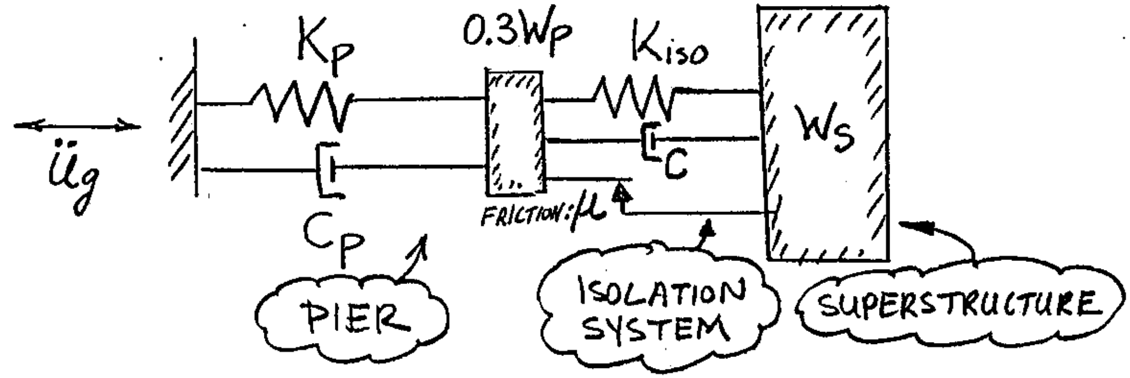
FIGURE 6

FIGURE 7



Frictional Properties of Woven Composite-Stainless Steel Sliding Interface





$$\xi_p = \frac{C_p}{2\sqrt{K_p m_p}} = 0.05$$

$$\xi_{iso} = \frac{C}{2\sqrt{K_{iso} m_s}} = 0.4$$

$$T_{PIER} = 2\pi\sqrt{\frac{0.3W_P}{g\,K_p}} = 0.2\text{ secs}$$

$$T_{iso} = 2\pi\sqrt{\frac{W_s}{g\,K_{iso}}} = 3\text{ secs}$$

$W_s = 8000$ kN , $m_s = W_s/g$

$W_p = 4703$ kN

$0.3W_p = 1411$ kN , $m_p = 0.3W_P/g$

$K_p = 147000$ kN/m

$K_{iso} = 3580$ kN/m

$\mu = 0.10$

FIGURE 8

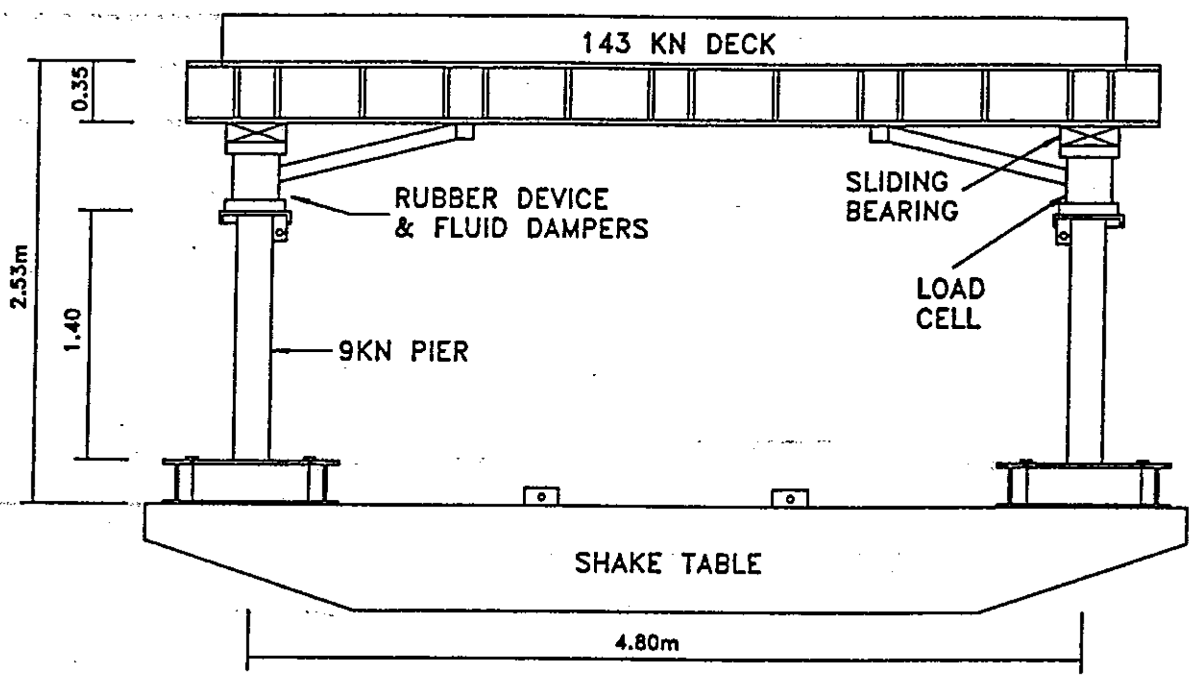
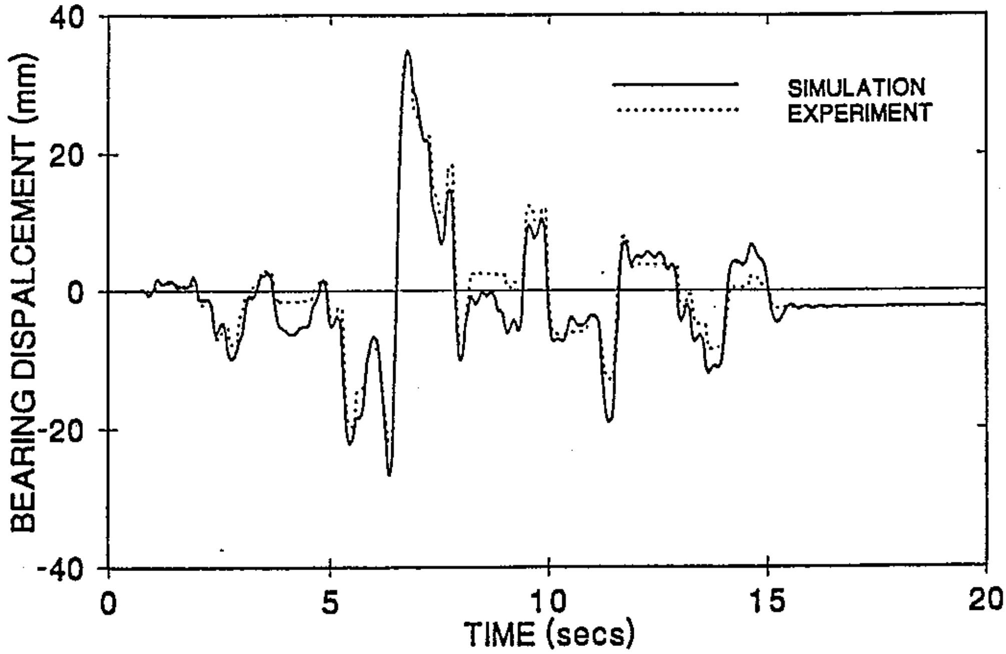

143 KN DECK
0.35
2.53m
1.40
RUBBER DEVICE
& FLUID DAMPERS
SLIDING
BEARING
LOAD
CELL
9KN PIER
SHAKE TABLE
4.80m

FIGURE 9

BRIDGE MODEL (S_{LENGTH} = 4), INPUT= JAPANESE LEVEL 2
G.C. 2 , 75%

μ=0.14 , T= 1.4secs (RUBBER DEVICE)



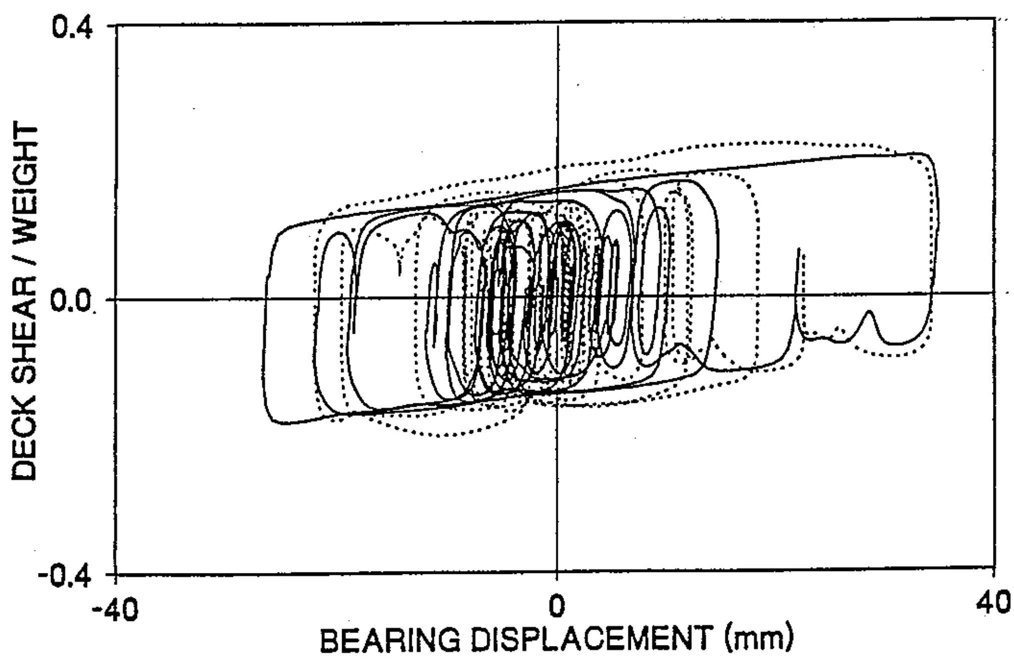


FIGURE 10

BRIDGE MODEL ($S_L = 4$), INPUT = JAP. LEVEL 2
G.C. 2, 75%

$\mu = 0.14$, $T = 1.4$ secs (RUBBER DEVICE)
$\xi = 0.47$ (FLUID DAMPERS)

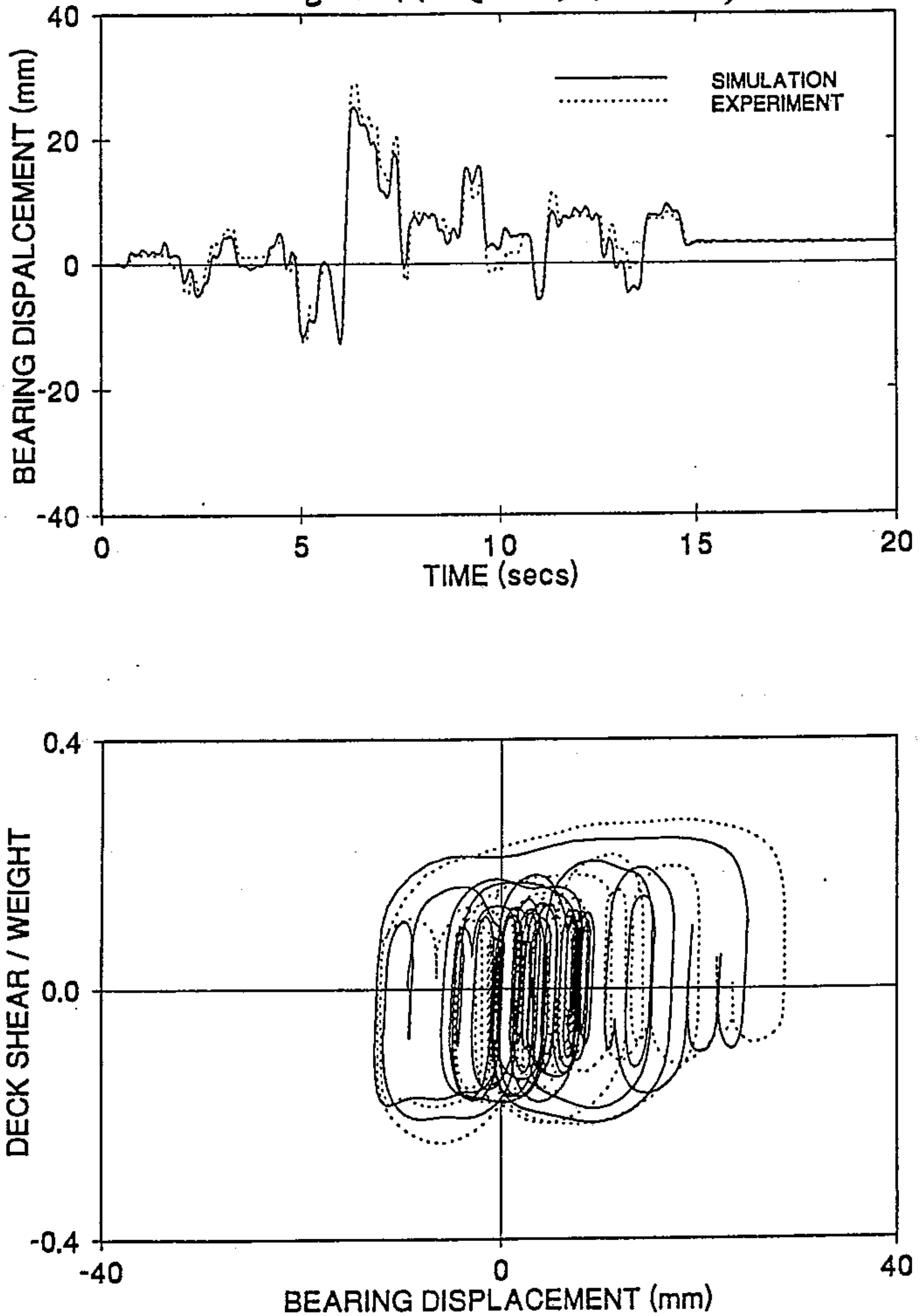
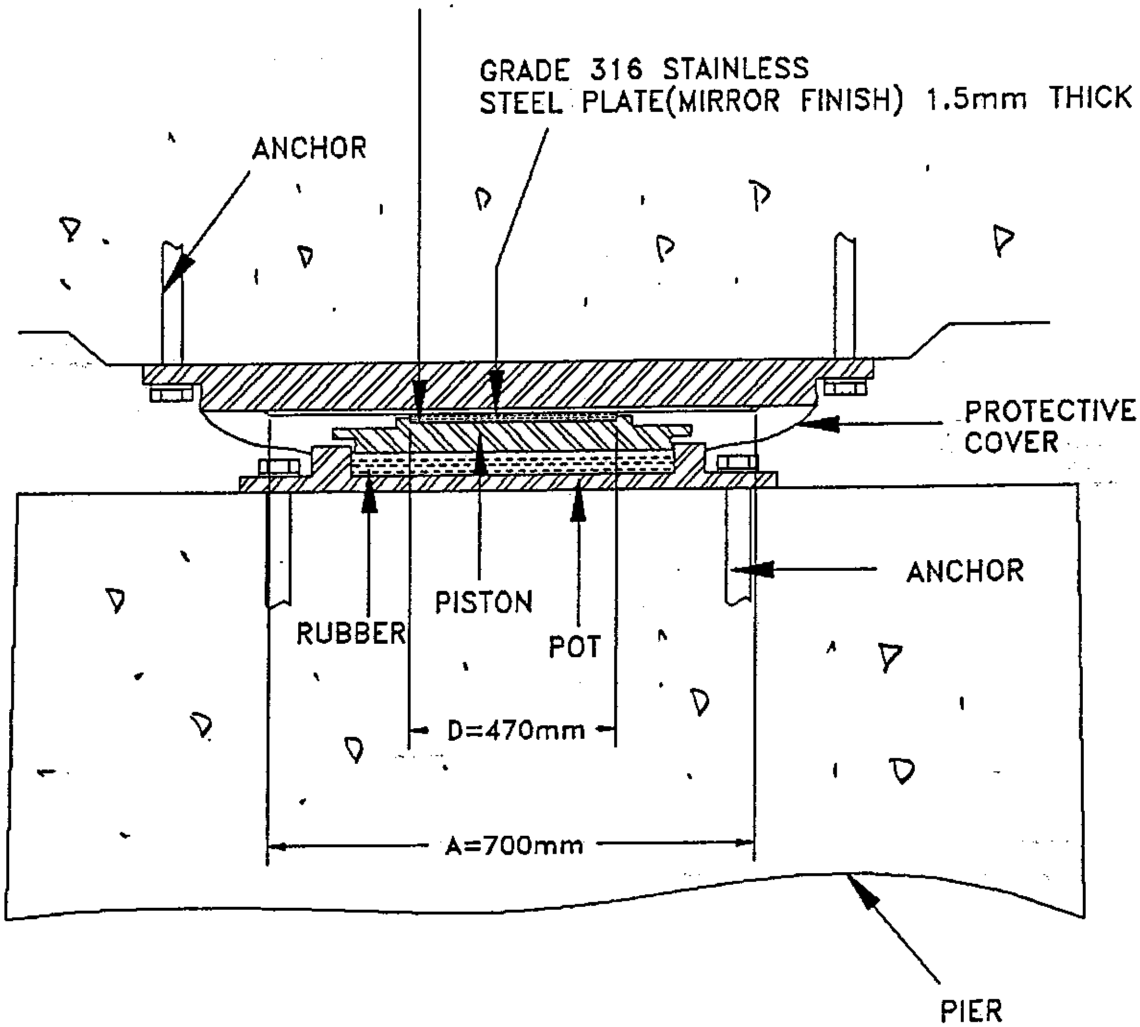


FIGURE 11

SLIDING BEARING (FOR AASHTO MOTION)

WOVEN COMPOSITE BEARING MATERIAL BONDED TO STEEL



NOTES: 1. POT MAY BE REPLACED BY SPHERICAL OR DISC SUPPORTING PART

2. A VARIETY OF MANUFACTURERS PRODUCE SLIDING BEARINGS. ANY BEARING IS ACCEPTABLE PROVIDED IT SATISFIES THE DIMENSIONAL AND MATERIAL CONSTRAINTS OF THIS DRAWING

3. PROTECTIVE COVER IS REQUIRED

FIGURE 12

RUBBER RESTORING FORCE DEVICE (FOR AASHTO MOTION)

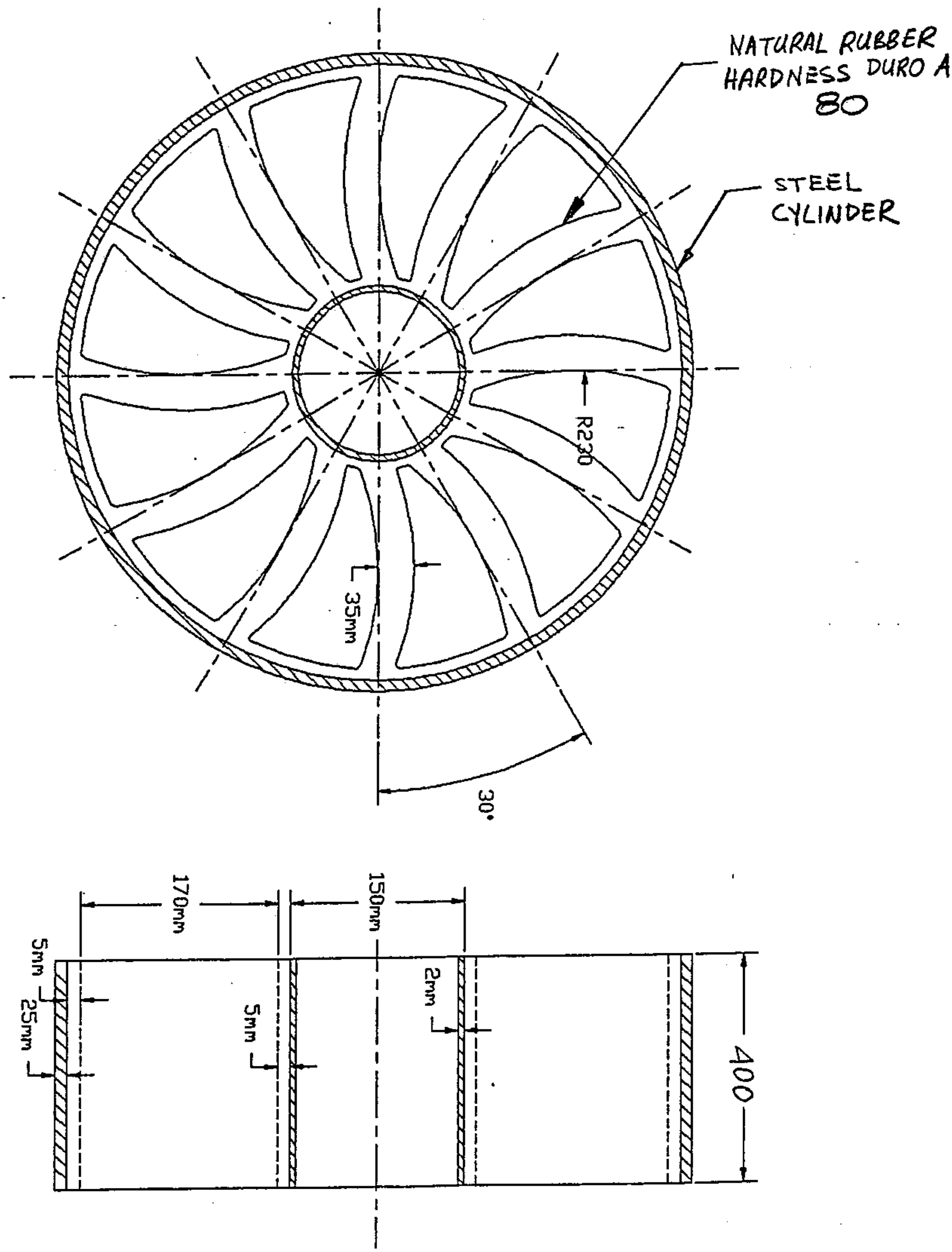
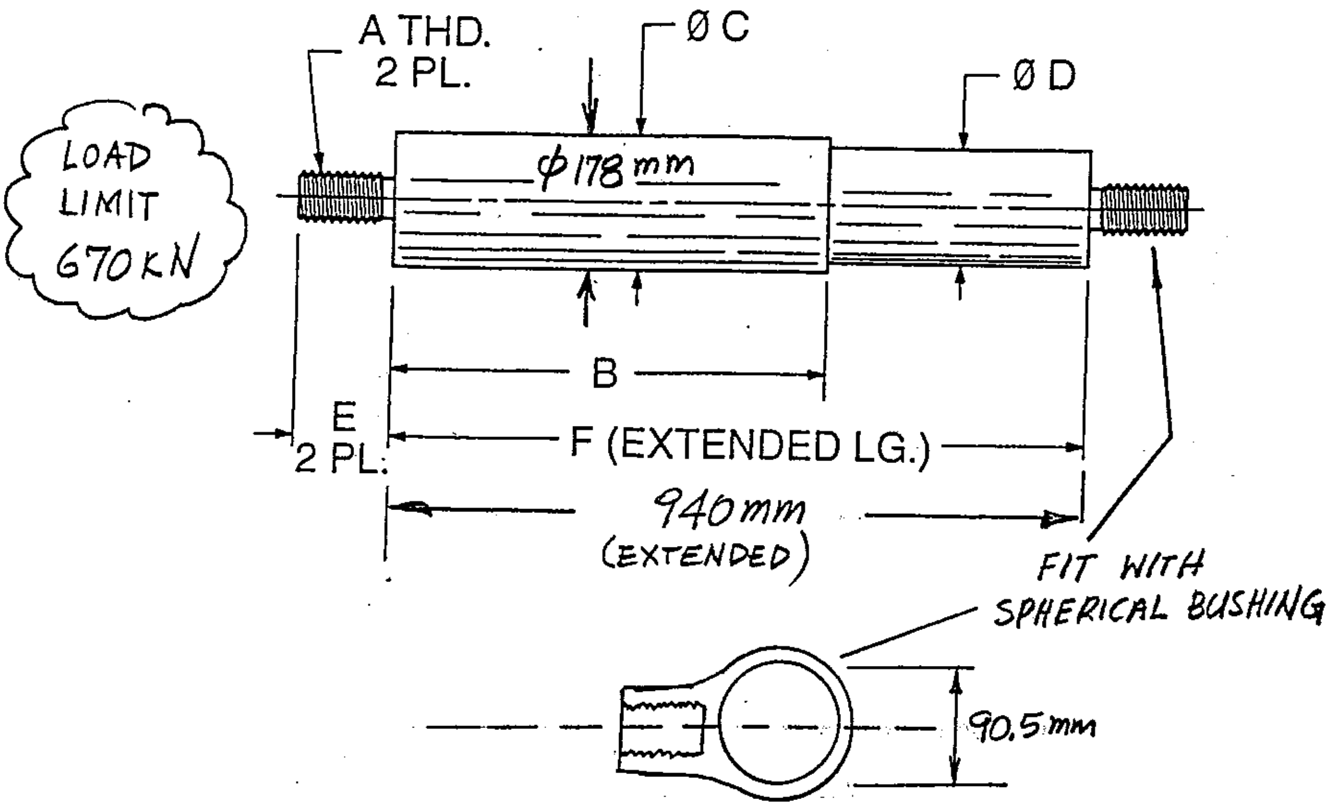


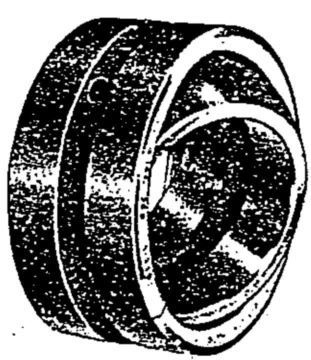
FIGURE 13

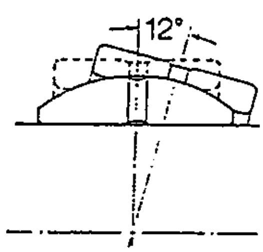
FLUID DAMPER (FOR AASHTO MOTION)



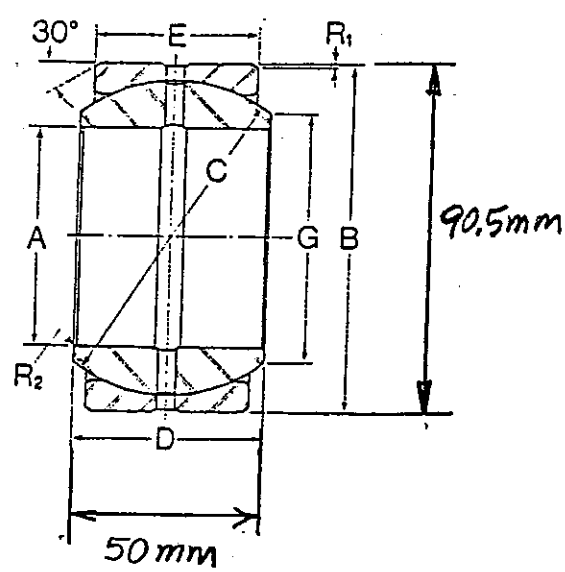
Self-Aligning Radial Bushings

Heavy Duty, Single Fractured, Self-Contained





Angle shown is based on maintaining full spherical contact.



ULTIMATE RADIAL LOAD = 1115 kN

ALLOWABLE RADIAL LOAD = 745 kN

FIGURE 14