Experimental Study on Reducing the Seismic Response of the Piers in Continuous Girder Bridges Using Low Friction Sliding Bearing Supports

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ABSTRACT

Authors have shown the superiority using the low friction sliding bearing supports (LFSBS) for the continuous girder bridge by the seismic response analysis. This paper inspects the validity of this system by a shaking table test for girder bridge models with two different LFSBS and a frame type bridge model. A model bridge is assembled by two H- shape steel piers and a steel girder. Accelerations, displacements and strains are measured and compared for three models. It became clear that in models with LFSBS piers vibrates in themselves, and displacement at the top of the pier and strain at the bottom of the pier is very small compared to that of the frame type bridge. The effect of using rubber type buffer at the end of the girder to reduce the large displacement of the girder is also clarified. The use of the buffer has no effect for the response of the pier.

1. Introduction

Many high damping bearing supports have been used to increase the seismic performance of bridges since 1995 Hyogo-ken Nanbu Earthquake in Japan. But in some cases these bearing supports became too big because of the small values of allowable stresses and demanded the large clearance between girder and abutment. Therefore recently the separate function type bearing supports have been adopted to small the bearings, in which sliding bearing supports have the function to support vertical loads only and high damping rubber works as the restoring force during the earthquake. But such structures with long natural periods have a fear of resonance on the soft soils and bearing supports are expensive.

On the other hand, the LFSBS is expected to develop the new bridge system, in which the inertia forces from the superstructures to the understructures are reduced, and the cost of the understructures and bearing supports are also reduced. Authors have shown the superiority using the LFSBS by the results of seismic response analysis for the continuous girder bridges[1)]. Same concept named all free continuous girder bridge with LFSBS has already been proposed by other researchers[2)]. But an inspection by experimental work has not been done yet.

This paper inspects the validity of this system by the shaking table tests for a girder bridge model with LFSBS and a frame type bridge. This paper also shows that using rubber type buffer at the end of the girder can reduce the large displacement of the girder.

The low friction bearing support was developed using the fiber reinforced and heat hardening resin, and the coefficient of friction (COF) is about 0.02 at the velocity of 2m/sec. To our surprise, this coefficient is almost 1/10 of the ordinary friction type support. Furthermore down sizing of the support and cost reducing is expected, because this material has twice the allowable surface pressure of the ordinary material.

2. Shaking table test of the model bridge

(1) Model bridge and low friction bearing supports

A model bridge is assembled by two H- shape steel piers and a steel girder (plate) of 1.75kN as shown in Fig.1. The span of the girder is 450mm and the height of the piers is 800mm. Two L shape steel beams are used to connect the bottom of the piers to the shaking table by bolts. Table 1 shows the material, the shape of cross section, and dimensions used for the model bridges. Table 2 shows the support conditions of the three model bridges tested in this research. The models 2 and 3 have LFSBS on the top of the piers. Fig 2 shows the circular shape LFSBS used for our experiment. The counterpart of a LFSBS is a plate coated by fluorine and pasted on the bottom of the girder.

(2) Items and locations of measurement

Fig.1 also shows the location of the measurement. Accelerometers were put on the girder, top of the pier A, and the shaking table. Similarly the displacement meters were attached to the girder, top of the pier A, and the shaking table. Strain gauges are pasted on the top and bottom of the pier A, and on the bottom of the pier B. Two strain gauges are pasted on the edge of the flange in one cross section.

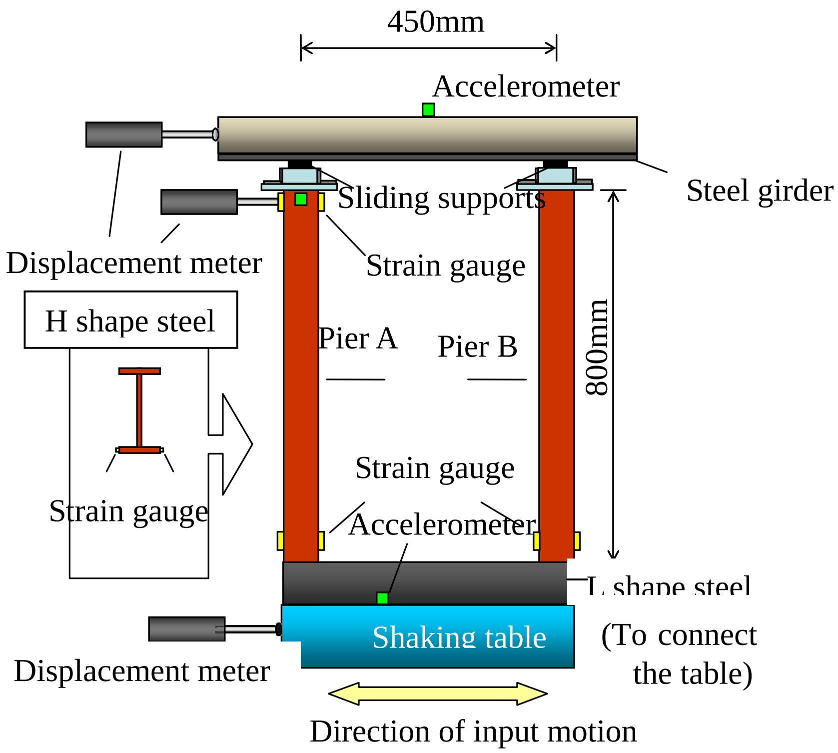


Fig. 1 Model bridge and arrangement of measurement equipment

Table 1 Material, Shape of cross section and dimension of component of model

	Material	Shape of Cross Section	Dimension (mm)
Girder	Steel	Rectangular	650 ×700× 50
Pier	Steel	H shape	100×50×5×7×875
Low friction sliding bearing support	Fiber reinforced & heated resin	Circle	ϕ 30

Table 2 Support conditions and coefficients of friction (COF)

	Support Conditions	Coefficients of Friction
Model 1	Rigid	—
Model 2	Low friction sliding bearing support	0.04 — 0.16
Model 3	LFBS & Grease	0.02 — 0.04

(3) Measurement of the friction coefficients

The characteristic of LFSBS depends on the surface pressure and velocity, and the larger the pressure and the velocity become, the smaller the coefficient of friction (COF) become. The area of the cross section is large compared to the weight of the girder, therefore the COF is expected to be larger than that in the real bridge. In other words, surface pressure in the experiment is about 1.2N/mm^2, but it would be 40N/mm^2 in real bridge, therefore the COF becomes more than 0.1 instead of 0.02 in our experiment. For this reason we prepared two different bearing supports for models 2 and 3, that is to say, LFSBS only for Model 2 and LFSBS with grease for model 3.

We conducted the measurement test of the COF of LFSBS prepared for models 2 and 3. In this test, the shaking table (ST) was moved with constant velocity to push the load cell installed between the frame column and steel girder as shown in Fig. 3. The velocities of the ST are 0.5, 5, 50, 100, 200 mm/sec. Fig 4 shows the relation of COF and velocities. The COF of LFSBS is more than 0.1, because the surface pressures are so small that small COF are not be obtained. Furthermore the faster the velocity becomes, the larger the coefficient of friction becomes in our test, because the velocity is so small. According to the reference [1)], the COF becomes maximum at the range of 100 – 200 mm/sec. These values are velocities used for our test.

The COF of LFSBS with grease is less than 0.04, and this value is near the COF of LFSBS realized in real situation.

From the experimental result of models 2 and 3, we can compare the effect of the COF on the dynamic behavior of model bridges.

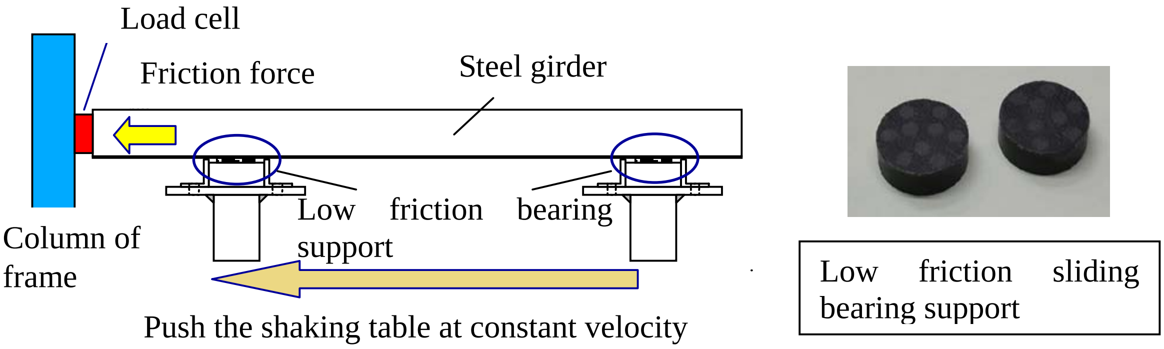


Fig.2 Measurement of coefficient of friction and friction bearing support

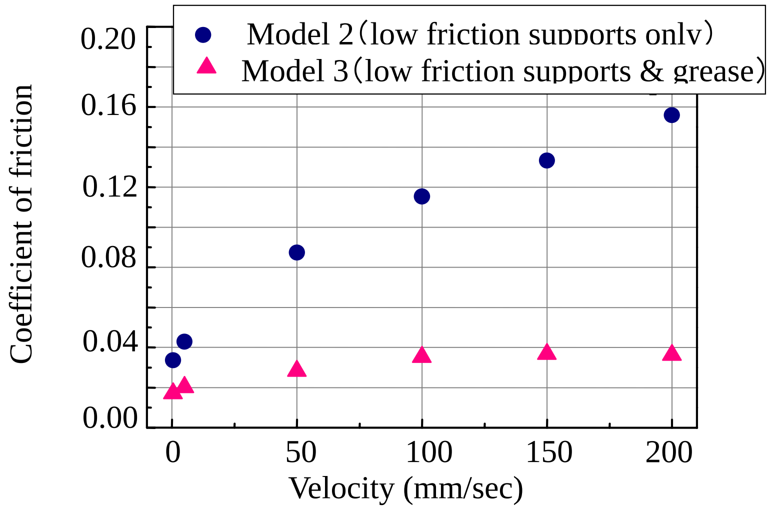


Fig.3 Relation of COF and velocity

(4) Cases of experiment

The natural period of the model 1 obtained by the free vibration test is 0.18 sec. Input waves of the shaking table are sine curves with periods of 0.7, 1, 1.5, 2, 2.5, and 3 times natural period of model 1. Table 3 shows maximum acceleration, period of input wave, and maximum velocity for the each test.

The model 1 were excited by 250, 350, and 450 gals, and the models 2 and 3 were excited by all maximum accelerations shown in Table 3. Some combination of large acceleration and long period of input waves are omitted from the table 3, because these cases beyond the limit exciting velocity of 230 mm/sec of the actuator.

If we can assume that the slide of the girder occurs when the inertia force of the girder (ma) equals the friction force(μmg) , response acceleration of girder(a_s) when slide of the girder begins is expressed as $a_s = \mu g$. Let us suppose that the COF of models 2 and 3 are 0.13 and 0.04 respectively, the slide of the girder begin 127 and 39 gals respectively.

Table 3 Test cases

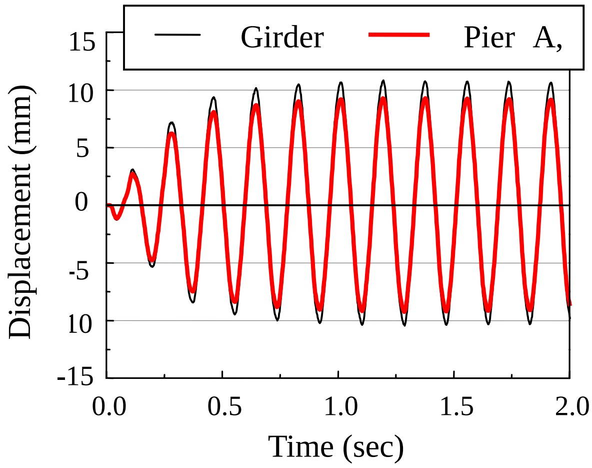
Case	acceleration	natural period (ratio)	velocity
1	50	0.126(0.7)	1.00
2		0.180(1.0)	1.43
3		0.270(1.5)	2.15
4		0.360(2.0)	2.86
5		0.450(2.5)	3.58
6		0.540(3.0)	4.30
7	150	0.126(0.7)	3.01
8		0.180(1.0)	4.30
9		0.270(1.5)	6.45
10		0.360(2.0)	8.59
11		0.450(2.5)	10.74
12		0.540(3.0)	12.89
13	250	0.126(0.7)	5.01
14		0.180(1.0)	7.16
15		0.270(1.5)	10.74
16		0.360(2.0)	14.32
17		0.450(2.5)	17.90
18		0.540(3.0)	21.49
19	350	0.126(0.7)	7.02
20		0.180(1.0)	10.03
21		0.270(1.5)	15.04
22		0.360(2.0)	20.05
23	450	0.126(0.7)	9.02
24		0.180(1.0)	12.89
25		0.270(1.5)	19.34

3. Test Results

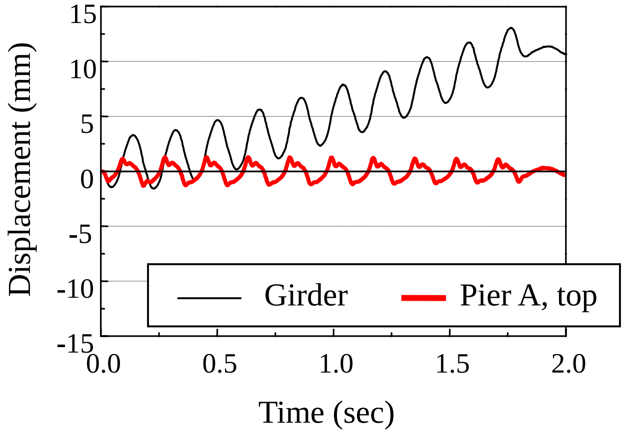
(1) Response comparison by time histories

Time histories of relative displacements of steel girder and the top of the pier A to ST, acceleration of steel girder and the top of the pier A, and strains at the bottom of the pier A are shown and compared in Figs. 4, 5 and 6 respectively. Shaking table were excited by the same period of natural period of Model 1 and the maximum acceleration of 250 gal, that is case 14. In the Model 1, relative displacements of the girder and the top of the pier are almost same, but in the Models 2 and 3, girder and pier behaved differently, and this shows the occurrence of the slide between girder and pier. In these models, the displacement of the top of the pier is very small compared to that of the girder.

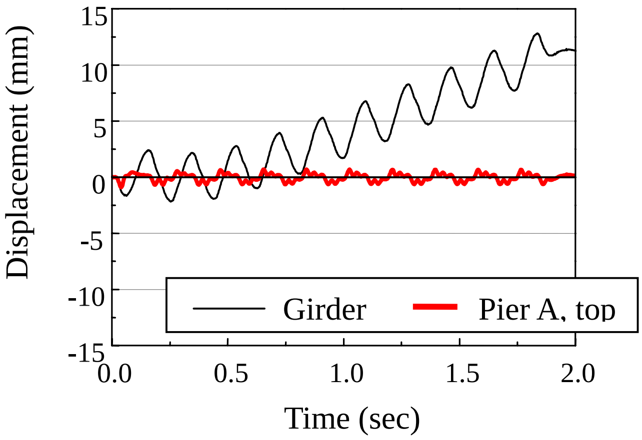
In the Model 1, response acceleration of the girder and the top of the pier are almost same and very large, but in the Models 2 and 3, girder and pier behaved differently. In the Models 2 and 3, the acceleration of the girder is very small because slide of the girder occurs for the force more than friction force, that is to say, excitation force to the girder are shut down by the LFSBS. On the other hand acceleration of the top of the pier is as large as that of the Model 1, but the period of excitation of the pier is very short. Therefore the



(a) Model 1



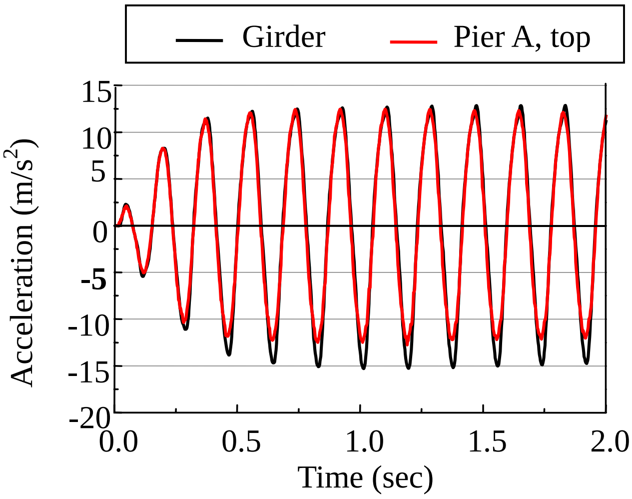
(b) Model 2



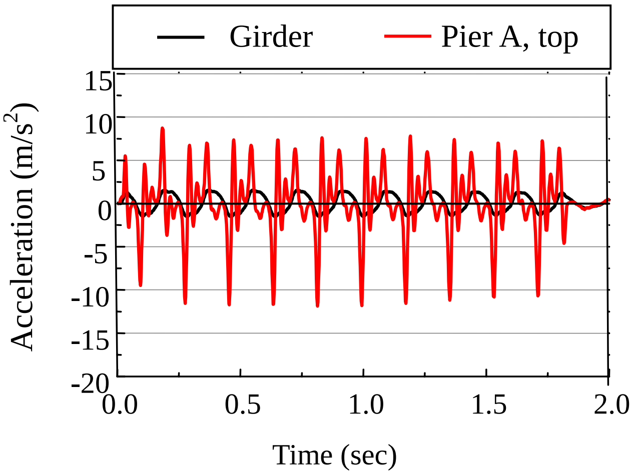
(c) Model 3

Fig.4 Time histories of displacements of the girder and the top of the pier A

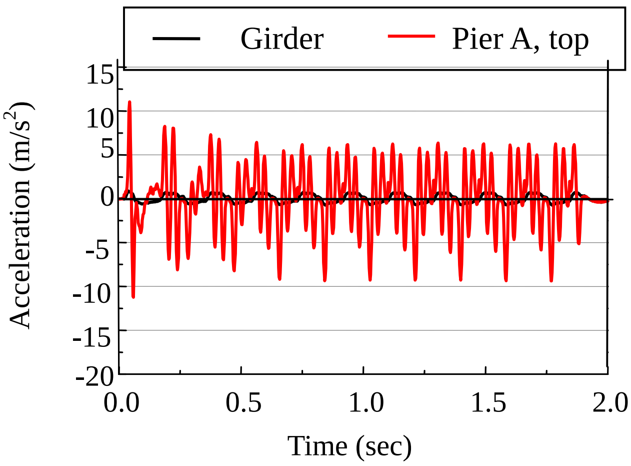
response displacement of the pier is small. Judging from these phenomena, it is clear that



(a) Model 1

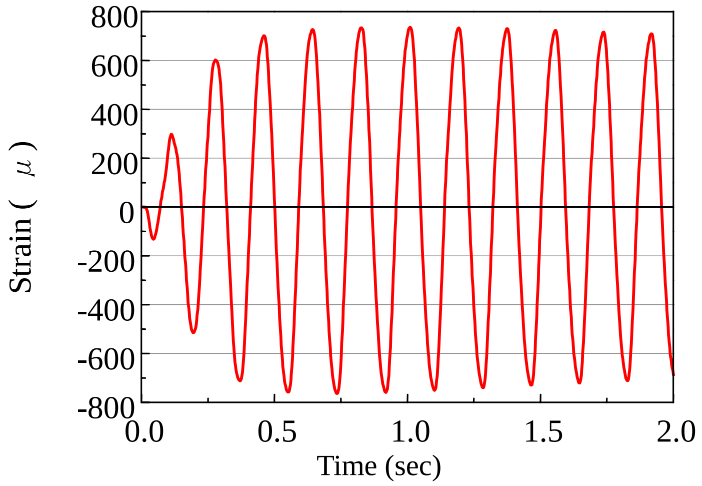


(b) Model 2

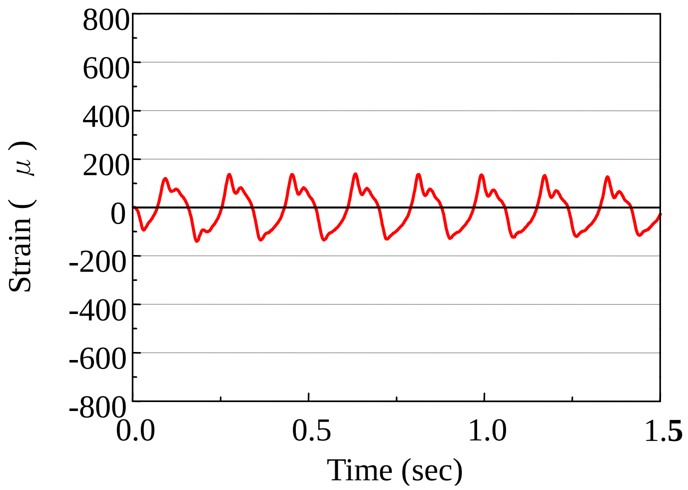


(c) Model 3

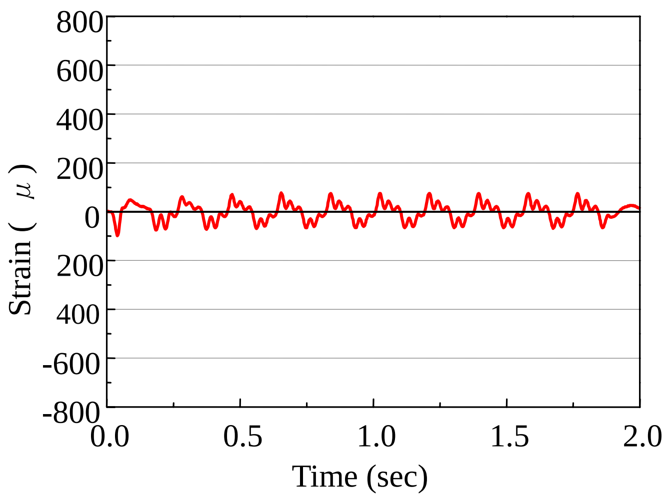
Fig.5 Time history of acceleration of the girder and top of the pier A



(a) Model 1



(b) Model 2



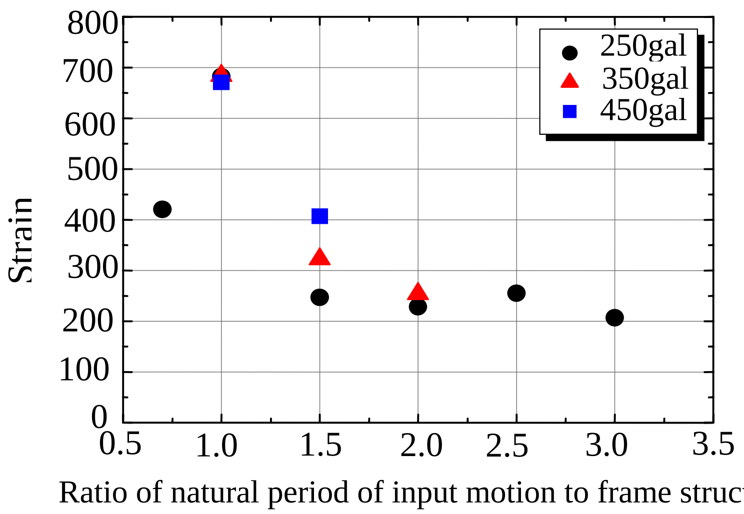
(c) Model 3

Fig.6 Time histories of strains at the bottom of the pier A in Models 2 and 3 piers vibrates in themselves.

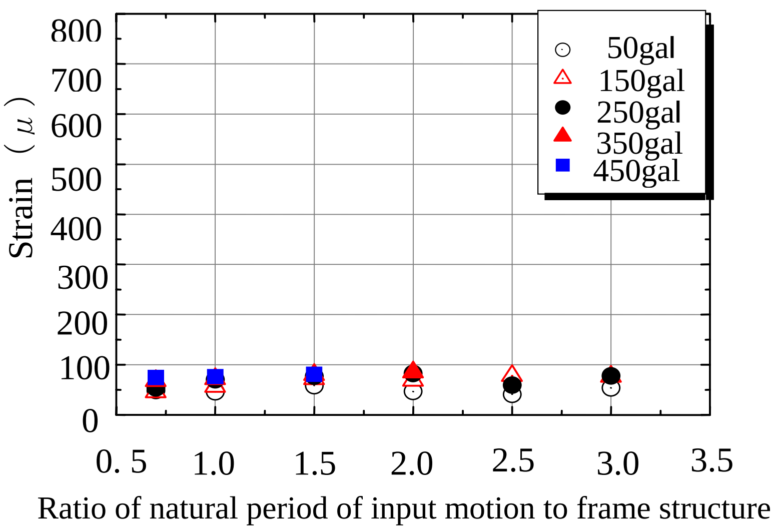
Moving our attention to the strain of the bottom of the pier in the Model 3, maximum strain is reduced to 10% of the Model 1 and 50% of the Model 2. From this we understand the merit using low friction bearing supports. That is to say, the seismic force for the pier with the LFSBS is the inertia force of the pier itself and very small value from the girder.

(2) Comparison by maximum values

Fig. 7 shows the maximum strain of the pier for Models 1 and 3. The resonance occurred in the Model 1 for the case such as the ratio of natural period of input motion to frame structure is 1. But the resonance did not occur in the Model 3, because the characteristics of natural period change before and after a slide. It is assumed that slide occurs at 40gals from the COF. Therefore the slide occurred from the input wave of 50 gals, so the maximum strains of the pier are almost same for the different amplitudes and periods of input waves.



(a) Model 1



(b) Model 2

Fig. 7 The maximum strain of the pier for Models 1 (above) and 3 (below)

4. Displacement control of the girder

In the bridge with LFSBS, girder and pier behave separately. Therefore the displacement of the girder would be large, and this may cause the collision of the girder to adjacent girder or the abutment, or the falling down of the girder. For this reason dumber or buffer for the control of the displacement, or protection system for the girder falling down. We conducted the simple experiment of collision and inspected the behavior of the girder and pier during the collision.

Buffer made by rubber with two different depths (5mm and 20mm) were used for Model 3. The cross section of the square rubber is 100mm^2.The stiffness of the buffer is shown in Table 4. The larger the depth is, the smaller the stiffness is. The period of input motion is 0.5 sec and maximum acceleration is 150 gals. The buffer is pasted to the column of the frame. The clearance between the girder and the buffer is 25mm. Fig.8 shows the sketch of the collision test.

Fig. 9 shows the time history of the absolute displacement of the girder. The collision occurred when the displacement became 25mm of the initial clearance. The observed collision numbers are five for the thick (soft) rubber and two for thin (stiff) rubber.

Fig. 10 shows the time history (from 1.5 sec to 4.5 sec) of the acceleration of the girder, and from this figure the increase of the acceleration by the collision is very clear, especially in the case used thin (stiff) rubber. We can recognize that the larger the stiffness of buffer becomes, the number of the collision decrease, but collision force for the girder increase. While the strain of the pier does not increase at the time of collision as shown in Fig.11, except the period of pier slightly increase.

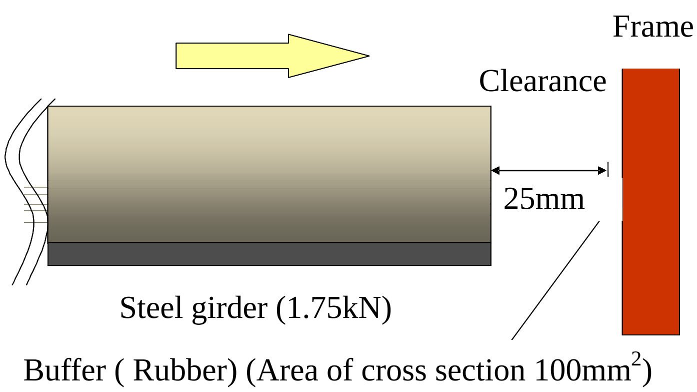


Fig.8 Outline of the collision test

Table 4 Depth and Stiffness of Buffer

Buffer depth (mm)	Stiffness (N/mm)
5	182.5
20	37.3

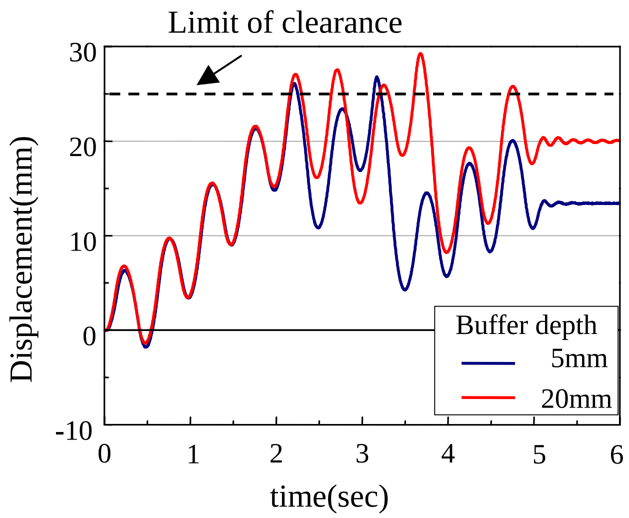


Fig.9 Displacement of the girder

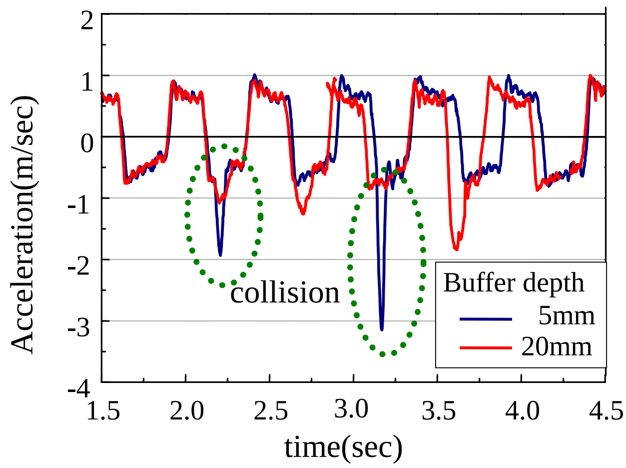


Fig.10 Displacement of the girder

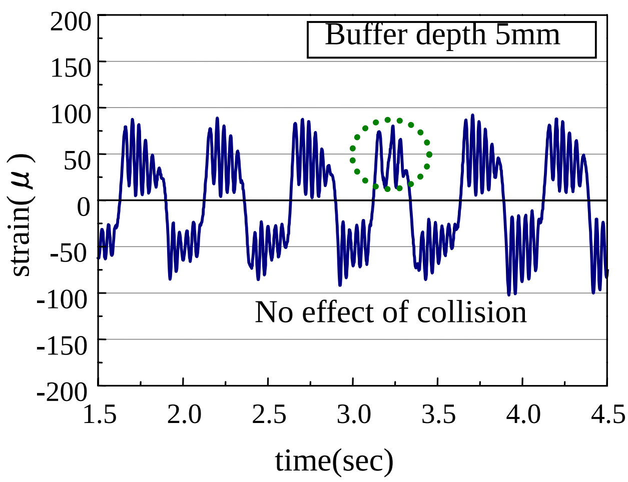


Fig.11 Displacement of the girder

5. Conclusion

This paper clarifies the effectiveness of bridge system with LFSBS by a shaking table test. It became clear that in models with LFSBS piers vibrates in themselves, and displacement at the top of the pier and strain at the bottom of the pier is very small compared to that of the frame type bridge. The effect of using rubber type buffer at the end of the girder to reduce the large displacement of the girder is also clarified, and the use of the buffer has no effect for the response of the pier.

The cost of the pier with LFSBS would be small compared to the pier with ordinal high friction bearing supports.

References

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