Behavior of Bearing Plate Type Bridge Bearings Under Traveling Load

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Although bridge bearings are important parts in bridges, they are subject to severe conditions for long periods of time. This might lead to damage, particularly if maintenance is poor. Macroscopic analysis of the inspection data on the Hanshin Expressway is provided. Then, the dynamic behaviors of bridge bearings under traveling loads were measured both before and after new bridge bearings were installed. Model tests with full-size bridge bearings were conducted to improve the functions of the bridge bearings. The major results are as follows. (a) Approximately 70 percent of the bearings on the Hanshin Expressway are plate bearings, and the number of damaged bridge bearings increases after 20 years of service. (b) Plate bearings that had been used for about 20 years no longer functioned well under traveling loads. The sliding function could not be fully restored, even by replacing the existing bridge bearings with identical new ones. (c) Rubber bearings (particularly pot bearings) are suitable for improving bridge bearing function.

The principal functions of bridge bearings are

1. To support the dead load of the bridge and the repetitive traveling load.
2. To prevent the constraint of the repetitive displacement of the girders caused by vehicle loads and temperature changes.
3. To prevent the unusual displacement produced in the substructure of a bridge during an earthquake from being transmitted to the superstructure of the bridge.

However, bridge bearings are often used for long periods of time under severe environmental conditions, and they are prone to corrosion caused by the accumulation of rainwater and dust leaking from the expansion joints. Bridge bearings are susceptible to damage because they are installed at the last stage of the erection process. In fact, considerable damage is inflicted on the body of bridge bearings and near bridge bearings in bridges that have been in service for a long time.

Replacing the bridge bearings is the best way to restore the bridge bearing function of an existing bridge in such a condition. However, it is difficult to replace bridge bearings when the bridge is in use, and it is not economical to replace them frequently, such as for a consumable item. In the future there will be a growing need for practical bridge bearings with durability. To date much of the research conducted to make bridge bearings more durable has been concentrated on the

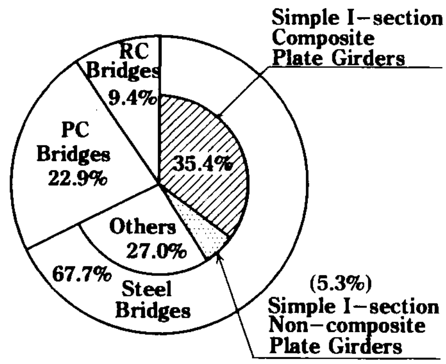


FIGURE 1 Assortment of bridges in Hanshin Expressway.

body of the bearing itself; almost nothing has been done to examine the influence on the main girders.

First, we analyzed the actual state of maintenance on the Hanshin Expressway. Second, we conducted a field test to study the behavior of bridge bearings before and after replacement of the plate bearings. Third, we conducted comparative laboratory tests using full-size model girders to compare the functions of various kinds of bridge bearings. These tests clarified the types of bridge bearings that are suitable for steel bridges.

Maintenance on the Hanshin Expressway

The Hanshin Expressway has been in service as a trunk road in the Kansai Region since 1964. Most of the approximately 160 km was constructed between 1964 and early 1994 and consists of urban elevated expressway. Figure 1 shows the assortment of bridges on the Hanshin Expressway.

Approximately two-thirds of these are steel bridges. A large proportion of those are simple I-section steel bridges with spans of approximately 30 m that were constructed in the 1970s. Furthermore, many of the bridge bearings installed in these bridges are plate bearings with capacities of about 100 metric tons.

Figure 2 summarizes the results of periodic visual inspections of the entire structures of the bridges except for the decks conducted at intervals of once every several years. Ranks AA to C in Part 1 in Figure 2 were determined by third parties or by the importance of each structure (Table 1). Figure 2 shows that about 20 percent of all damage is classified as Rank A, and most of the damage consists of both damage to the bridge bearings and fatigue cracks.

Table 2 summarizes the actual conditions of the abnormalities in bridge bearings. There is considerable damage to plate bearings, which account for approximately 67 percent of all bearing stock.

In particular, a large number of set bolts used for assembling were damaged. These bolts were attached to provide temporary bearing when the bridges were erected and have no effect on the bridge bearing functions. Other damage that was identified was unusual spacing and contact with the side block, but these problems revealed functional deterioration caused by temperature changes. The deterioration of the functions of the bridge bearings themselves and the subsequent effects on the girders were not, in fact, inspected because of the structural details. Fatigue cracks, on the other hand, were mostly confined to the intersection between the main girder and the cross beam or sway bracing. Recently, however, the fatigue cracks shown in Figure 3 have developed on a frequent basis. This evidence indicates that the causes of the fatigue cracks are secondary stress and repetition accompanying a decline in the bridge bearing function under traveling loads and that

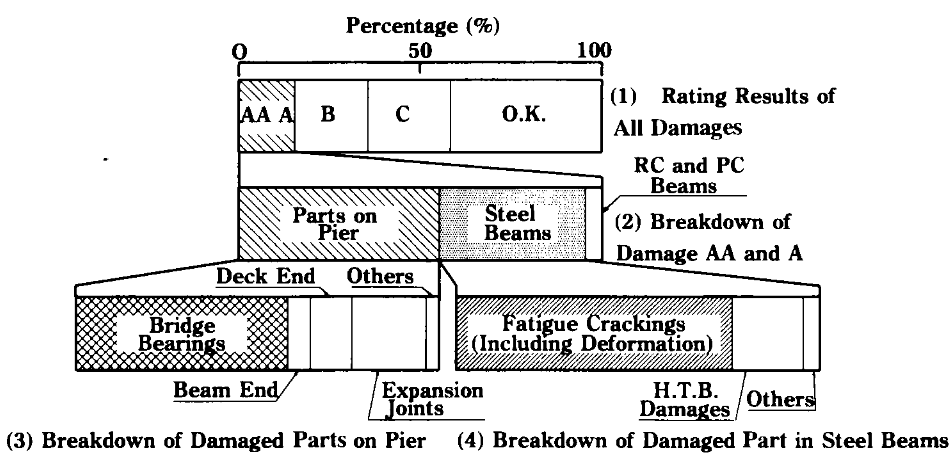


FIGURE 2 Results of bridge inspections.

TABLE 1 Ranking of Damages

Ranking of Damages	Criteria for rating of damage
AA	The damage is very serious, and emergency repair is needed.
A	The damage is serious, and repair is required.
B	The damage requires repair as needed.
C	The damage is minor but should be repaired as needed.
O.K.	For cases other than those mentioned above.

these bridge bearings should be replaced to eliminate risk.

Field Tests on Functions of Bridge Bearings

Method of Field Testing

In many cases old bridge bearings are replaced with identical bearings to restore the bridge to its original condition, but because this replacement work is done under service conditions, it is not easy to restore the bridge to its original quality and performance potential. For these reasons we conducted a field study on the behaviors near bridge bearings before and after replacement. Figure 4 is a general view of the target bridges that we studied, and Table 3 describes the structures of the old and new plate bearings. The bridges are continuous, standard simple I-section bridges that have been in service for 22 years. During this period the bridge bearings had not been replaced. However, all bridge bearings in several spans including those of the target bridge were replaced because some of the bridge bearings developed damage such as cracks in the mortar bed or contact with the side block. The field study involved dynamic measurements with both a wire strain gauge and a contact-type deflection sensor at three stages: before the replacement, just after the replacement, and 1 year later.

Field Test Results

Figure 5 provides examples of the field measurement results. Each axis is the amplitude of dynamically measured data by through traffic vehicles. The stress σc in the center of the span of the external main girder is stress that is believed to be proportional to the weight of the vehicles. The measurement values were scattered broadly according to the crossing position of the vehicles and their speed, although the regression line is provided in Figure 5. The closed symbols in Figure 5 represent the result of F.E.M. analysis; the actual bridge was modeled by using three-dimensional shell elements, and the design load was loaded (T-20, equivalent to a two-axle vehicle weighing 20 metric tons). Our results are summarized below.

1. The movable bearing must move horizontally by deflection of the main girder, but there was almost no

TABLE 2 Conditions of Abnormalities in Bearings (Rank A)

	Type of Bearing*								
Type of damage	LB	PB	Ro	Pi	Pv	PiR	PvR	Others	Total
Substance of bearing	13	138	50	1		4	1	12	219
Subsidence of bearing	33	112		8					153
Cracking on base concrete	18	18	3					1	40
Edge of bearing	3								3
Set bolts for assembling	8	1,273	46	16	2	5	2		1,352
Anchor bolts	4	13	2	1					20
Corrosion Inside		2	10			2	4	1	19
Corrosion Outside	14	29	1	2					46
Unusual spacing of bearing	48	266	11			2	2		329
Contact with side block	19	257	322			14	29	6	647
Abnormal noise			4				3		7
Others	2	27			2	4	1		36
Total Number of Rank A	146	2,039	407	27	4	20	38	18	2,699
(%)	(3.2)	(8.7)	(12.4)	(1.1)	(1.4)	(10.0)	(18.3)	(11.5)	(7.7)
Total Number	4,587	23,501	3,289	2,518	296	201	208	391	35,001

*: LB:Linear Bearing, PB:Plate Bearing, Ro:Single Roller Bearing, Pi:Pin Bearing Pv:Pivot Bearing, PiR:Pin and Multi-Roller Bearing, PvR:Pivot Roller Bearing

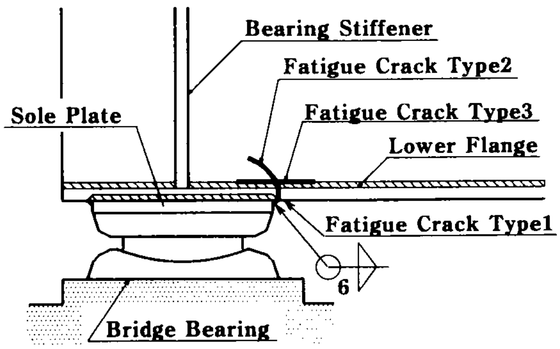


FIGURE 3 Fatigue cracks near bridge bearings.

horizontal movement of the movable bearing before replacement. It increased threefold after replacement and by about eight times 1 year after replacement, and it tended to approach the analytical values. However, it was still only about 44 percent of the analytical value even 1 year later.

2. The rotation angle on the movable bearing fell about 58 percent just after replacement in comparison with that before replacement, but it was 1.5 times the original value after 1 year. A comparison of these results with the analysis results indicates that the value for the fixed bearing is almost identical to the analysis value just after replacement and that the value for the movable bearing point is almost identical to the analysis value before replacement and 1 year after replacement. The rotation angle on the fixed bearing was reduced to a value identical to the analysis results, provided that there is complete constraint by replacement, and it remained unchanged 1 year later.

3. The stress σf on the movable bearing was changed little by the replacement, and its value was identical to the analysis value for the fixed bearing.

Experiment with Full-Scale Model Bearings

Experimental Method

We conducted a series of comparative laboratory tests on various types of full-size bridge bearings on the basis of the results of the field study. Figure 6 shows the test mock-up. The dimensions and specifications of the model girder were matched to those of the target bridge. At the same time a reaction force of 50 metric tons equivalent to a dead load was continuously loaded at the bearing point by PC rods, and a force equal to the traveling load was loaded at the center. Table 4 shows the specifications of the bridge bearing used in the test. For comparison, a pin-roller bearing was used as a model under an ideal condition. During the tests a pin bearing was fixed as the bridge bearing.

Experimental Results

Figure 7 shows examples of the relationship between P1 and the amount of horizontal movement or the rotation angle. At a low load horizontal movement is constrained in the rubber bearing. When the amount of horizontal movement per unit of load in the high-load area (15 to 25 metric tonf) was compared by taking the pin-roller bearing load as 100 percent, the following results were obtained: approximately 60 percent for BP-A1 and BP-A2, in which the horizontal sliding surface was equipped with fixed lubricants; between 66 and 75 percent for BP-A3, in which the horizontal sliding surface was a polytetrafluoroethylene (PTFE) plate, and for BP-A4 and a pot bearing case; and approximately 85 percent for the rubber bearing. The rotation angle of the plate bearing was, in all cases, smaller than that of the pin-roller bearing. However, the rotation angles of

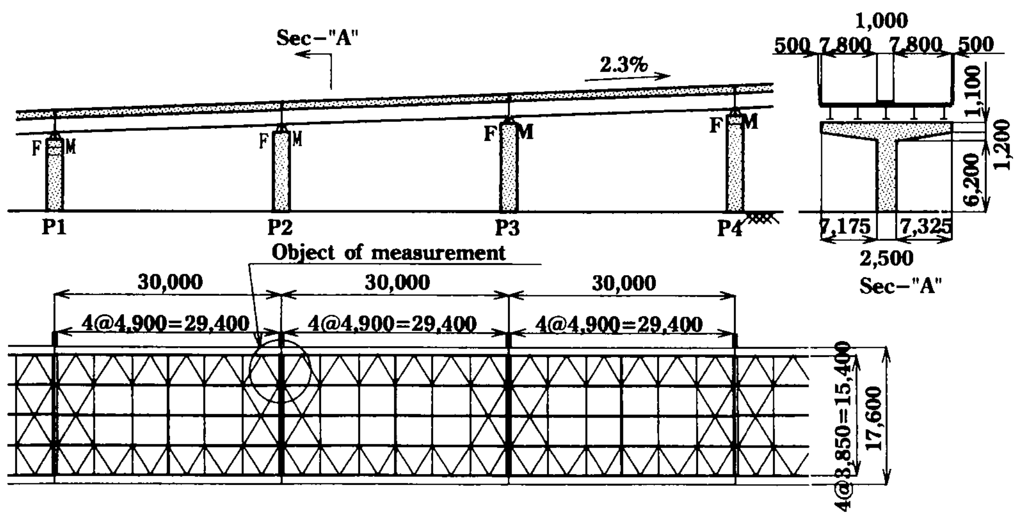
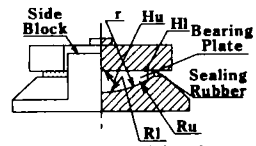


FIGURE 4 General view of target bridges.

TABLE 3 Comparison of Bearings Before and After Renewal

Bearing	Radius of Curvature r(mm)	Surface Condition* Hu	Hl	Ru	Rl
Existing Bearing	500	M.D.	G	G	M.D.
Renewal Bearing	210	SUS	PTF	G	M.D.

* :See Ap.Fig
M.D.:Molybdenous Disulfide Coating
G:Inlaid with Graphite
SUS:Welded with SUS316 Thin Plate(2mm)
PTF:Set on PTFE Plate(4mm)



AP.FIG. Typical Section

the pot bearing and the rubber bearing were larger. Figure 8 presents the longitudinal-direction strain distribution of the lower flange at the front of the sole plate and the vertical-direction strain distribution of the girder web per unit of load (stress at right angles to Type 3 cracks in Figure 3). In both cases strain convergence is seen in the front surface of the sole plate. Although overall the plate bearing provided higher values than the pin-roller bearing, those of the pot bearing and the rubber bearing were either the same or lower. In the case of the pot bearing in particular, the value was low (ϵ = 56 percent and ν = 96 percent).

Conclusion

The actual state of maintenance of bridge bearings on the Hanshin Expressway was investigated by a field study of

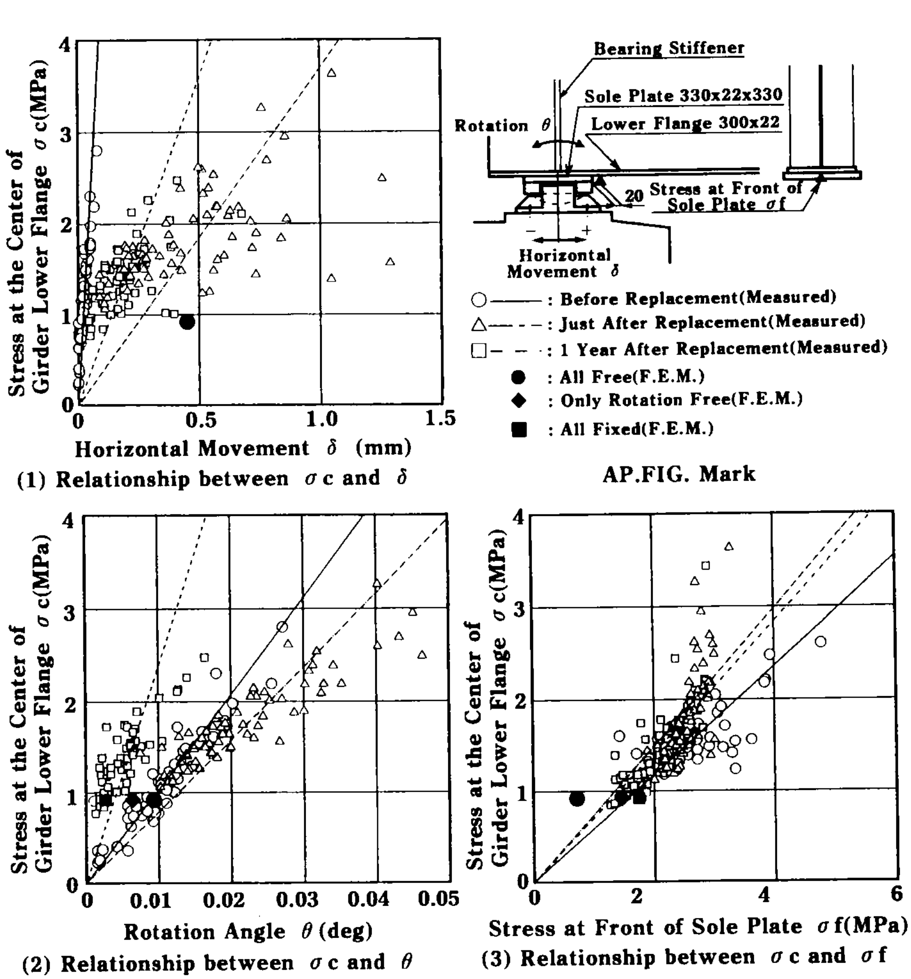


FIGURE 5 Field measurement results on movable support.

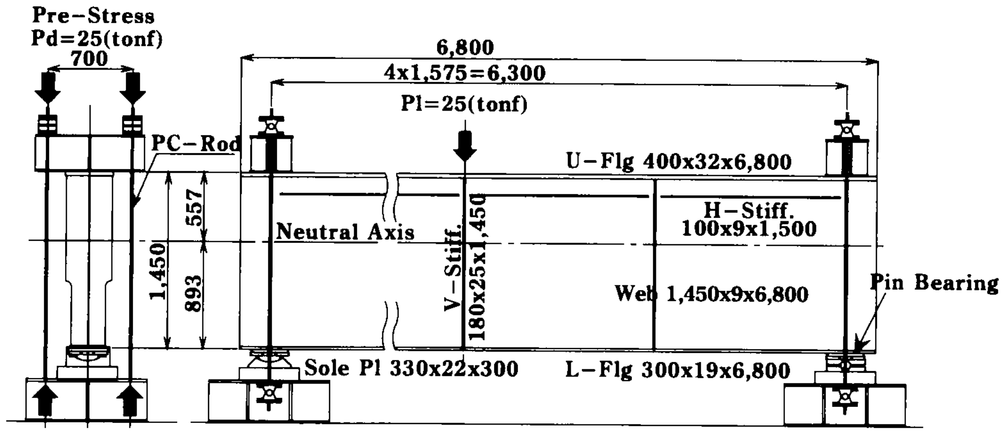
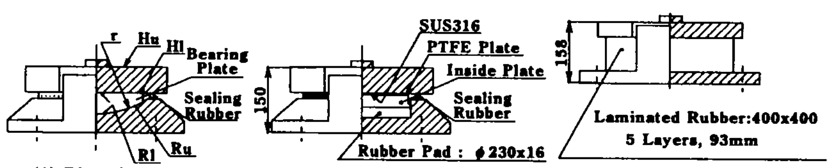


FIGURE 6 Test mock-up.

TABLE 4 Comparison with Characters of Test Bearings

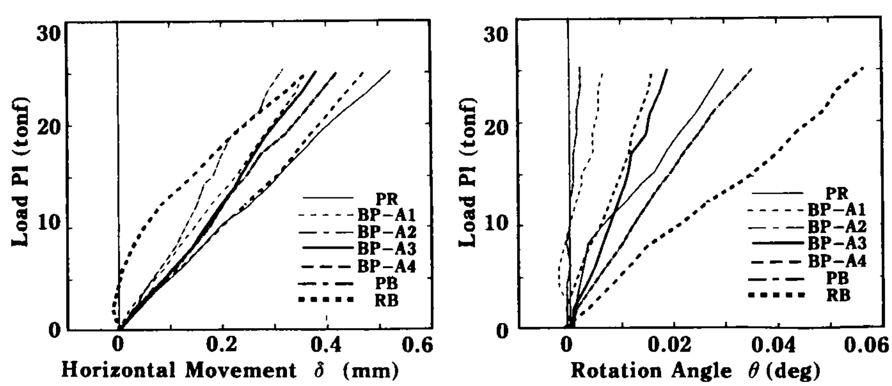
Mark		BP-A1*	BP-A2*	BP-A3*	BP-A4*	PB**	RB***
Radius of Curvature r(mm)		500	210	210	210		
Surface Condition	Hu	M.D.	M.D.	SUS	SUS	SUS	Rubber
	Hu	G	G	PTFP	PTFP	PTFP	
	Ru	G	G	G	PTFC	Rubber	
	Rl	M.D.	M.D.	M.D.	PTFC		

*,**,***:See AP.FIG
M.D.:Molybdenous Disulfide
G :Inlaid with Graphite
SUS :Welded with SUS316 Thin Plate(2mm)
PTFP:Set on PTFE Plate
PTFC:PTFE Powder Coat



(1) Plate Bearing (2) Pot Bearing (3) Rubber Bearing

AP.FIG Typical Section



(1) Relationship between Pl and δ (2) Relationship between Pl and θ

FIGURE 7 Test results for movable support.

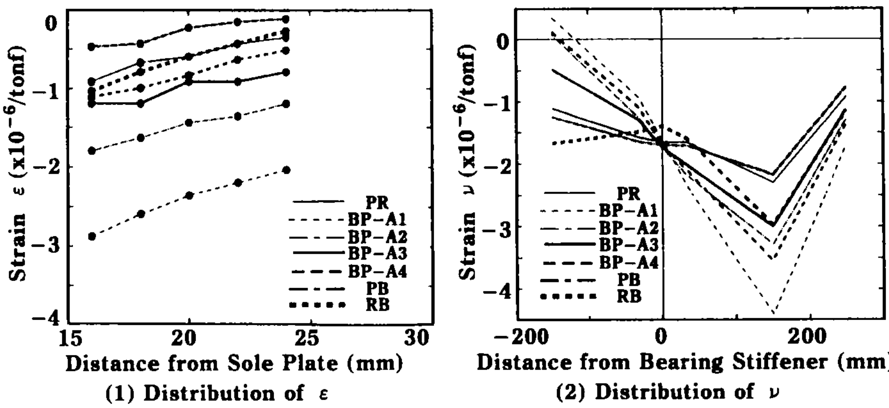


FIGURE 8 Strain distribution near sole plate on movable support.

the behavior near the bridge bearing before and after replacement of the plate bearings. We performed comparative tests on models equipped with various types of full-size bridge bearings. The results are summarized below.

1. Periodic inspections revealed damage to the plate bearings, which accounted for about 70 percent of all the bridge bearings, and extensive fatigue cracks in the steel girders.

The sliding function of the bridge bearings has not been fully inspected because of problems with structural details.

2. The horizontal sliding function of plate bearings inlaid with graphites that have been in use for roughly 20 years had declined sharply.

3. Replacing bridge bearings with plate bearings with a PTFE plate as their horizontal sliding surface improved their horizontal sliding function. However, those bridge bearings are not sufficient to deal with the minute displacement caused by the traveling load, as would be expected from the design.

4. There were cases in which it was impossible to improve the rotation function of plate bearings by replacing the bridge bearings.

5. Stress in the bridge axial direction of the lower flange near sole plates was reduced little by replacement.

6. The function of the plate bearings subject to a traveling load can be improved by using PTFE plates on their sliding surfaces, but it is still insufficient.

7. Tight rubber bearings or pot bearings provide excellent performance under traveling loads. In particular, tight rubber bearings are effective at preventing fatigue cracks in the main girders.

It will be necessary to develop both a method of inspecting the sliding functions of bridge bearings and bridge bearings with superior durabilities.