Transition and Recent Knowledge of Bridge Bearings in Japan

Tetsuo SANTO
Japan Railway Construction , Transport and Technology Agency, Japan

Jiro SAITO
OILES CORPORATION, Japan

Koichi MASUDA
OILES CORPORATION, Japan

SUMMARY
Construction of the Shinkansen is proceeding in Japan. Almost 50 years have passed since the beginning of the construction of the Tokaido-Shinkansen which opened in 1964. The Shinkansen railway's total distance is over 2800 km, inclusive of the Tohoku- and Kyushu- Shinkansen which opened in 2011.
During these times many earthquakes occurred in Japan. Experiencing many big and small earthquakes, we have been changing regulations and specifications. Above all, securing the seismic performance of the bearing by combining various devices are important items to prevent falling bridges.
We will introduce Japan's railway bridge bearing type and design method. Also we will report the status of bridge bearings influence of "The 2011 off the Pacific coast of Tohoku Earthquake" .

Keywords: Japanese Railway, Bridge bearing, Stopper, Seismic design

1. INTRODUCTION-HISTORY OF BRIDGE IN JAPAN (INCLUDING SHINKANSEN)

It is said that Japan's modern bridge history began with the Meiji Restoration. At that time, Japan imported technology introduced in Western countries, as well as the bridge itself, and constructed cast iron, wrought iron bridges. In Japan, bridge construction began in 1901, the time when steel making started.[1)]
During the period of high economic growth from infrastructure development after World War II, manufacturing bridges in the country became active, most notable of which was the opening of the Tokaido-Shinkansen in 1964. It will soon be 50 years from the opening of the Tokaido-Shinkansen, and the total distance of the Shinkansen railway is over 2,800 km. In addition, the Hokuriku-Shinkansen, Hokkaido-Shinkansen is currently under construction.
Table 1.1. shows the large-scale earthquakes that occurred in that time. This has expanded the requirements for high performance of the bridge bearing.

Table 1.1. Chronology of the construction of the Shinkansen and large scale earthquake

Line	Open	Interval	Distance (km)
TOKAIDO	1964	TOKYO - SHIN-OSAKA	552.6
SANYO	1972	SHIN-OSAKA - OKAYAMA	180.3
SANYO	1975	OKAYAMA - HAKATA	463.7
Off the Coast of Miyagi Prefecture earthquake in 1978 (M7.4)			
TOHOKU	1982	OMIYA - MORIOKA	505.0
JOETSU	1982	OMIYA - NIGATA	303.6
TOHOKU	1985	UENO - OMIYA	27.7
TOHOKU	1991	TOKYO - UENO	3.6
YAMAGATA	1992	FUKUSHIMA - YAMAGATA	87.1
The Southern Hyogo Prefecture earthquake in 1995 (M7.3)			
NAGANO	1997	TAKASAKI - NAGANO	117.4
AKITA	1997	MORIOKA - AKITA	127.3
YAMAGATA	1999	YAMAGATA - SHINJO	61.5
TOHOKU	2002	MORIOKA - HACHINOHE	96.6
Off the Coast of Miyagi Prefecture earthquake in 2005 (M7.2)			
Mid Niigata Prefecture Earthquake in 2007 (M6.8)			
The Iwate-Miyagi Nairiku Earthquake in 2008 (M7.2)			
TOHOKU	2010	HACHINOHE - SHIN-AOMORI	81.8
The 2011 off the Pacific coast of Tohoku Earthquake (M9.0)			
KYUSHU	2011	HAKATA - KAGOSHIMA-CYUOU	256.8
		TOTAL Distance	2865.0

2. BEARING USED IN THE RAILWAY BRIDGE

Bridge bearing unit has three roles.

1) support vertical and horizontal force
2) follow movement
3) follow rotation

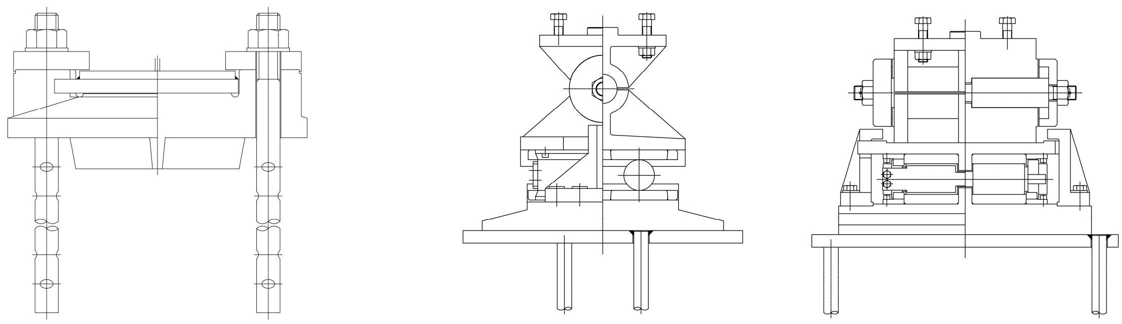
Although this seems to be universal, it can be said in the quake-prone Japan that supporting horizontal force is especially important. There are various types depending on the application timing and production. We will introduce the features and structures from the early days to the most recent.

2.1. Line Bearing

Figure 2.1.(a) shows the structure of Line Bearing. It is the bearing of a simple structure that is configured of the upper shoe serving as a sole plate and R processed cast iron under shoe. Shoe below the plane had been originally square, but improved and made oval by (old) JAPAN NATIONAL RAILWAYS in 1920, also known as the Oval Bearing. Height structure of this bearing can be kept low for the structure is simple, but from that, there is a phenomenon that the contact surface of the steels will corrode, or scrape off and will not move, in recent years almost have none been adopted.

2.2. Roller Bearing

Roller Bearing is a bearing that has been devised to follow the movement of the bridge, rollers sandwiched between cast iron upper shoe and under shoe. There is a record that it has been used in the (old) JAPAN NATIONAL RAILWAYS bridge of the Abukuma River in 1895, which is considered to be Japan's early Rolling Bearings . At that time, this type of bearing could only follow the movement of the bridge, not the rotation. Around 1915, it was improved to be able to follow the rotation by placing a pin on the top of the roller as Figure 2.1.(b)[1] This type of bearing is called a Pin- Roller Bearing, and can be seen even today in many parts of Japan. Bridges with Pin-Roller Bearing uses a device called Pin Bearing which does not use rollers for fixed support. However, many phenomenons of the rollers falling off during earthquakes has been confirmed, in recent years many have been replaced into Rubber Bearings and Sliding Bearing which we will introduce later.



(a) Line Bearing (b) Pin-Roller Bearing

Figure 2.1. Old Type Bearing

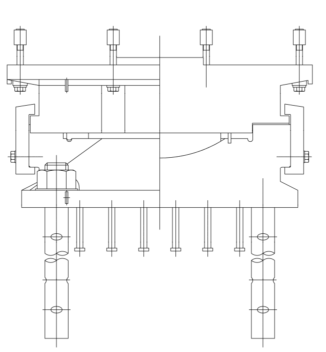
2.3. Sliding Bearing

Figure 2.2. (a), (b) shows the structure of the BP-A Bearing and Pivot Sliding Bearing that is currently used primarily in steel railway bridge. Both structures are very different, but for the slip plane, Bearing Plate of high-strength brass casting, embedded with graphite components is used. This applies to the technology of Sliding Bearing, which is standardized criteria and test methods by "Design Standards For Railway Structure and Commentary (Steel and Composite Structures)" [2] as Regulation of Steel Bridge Bearing SRS31. This material has been confirmed to ensure long term slip performance

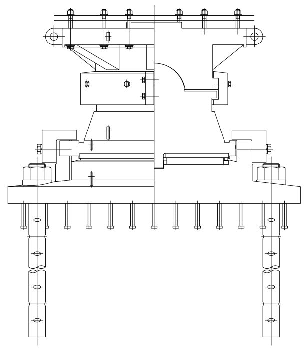
sustainability and durability.
BP-A Bearing achieved both following the movement of the bridge on a plane surface of the Bearing Plate, and following the rotation of the bridge on the semi-spherical face.
In addition, BP-B Bearings which sealed rubber for bridge rotation and PTFE sliding plate, has been adopted in many road bridges but not as much in railway bridges.

2.4. Pivot Bearing

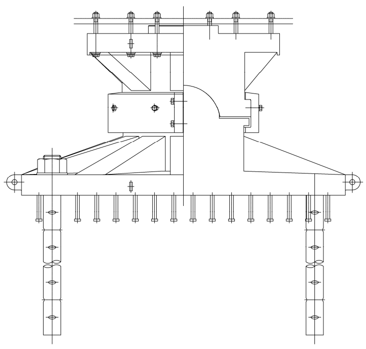
Figure 2.2. (c) shows the structure of the Pivot Bearing. Pin Bearing mentioned before is only able to follow the rotation of the track direction, but the Pivot Bearings is able to follow the rotation in all directions in order to receive a reaction force on the semi-spherical face. Pivot Sliding Bearing is often used in large-scale bridges, and in recent years, it has been adopted in Sendai Subway “Tatsunokuchi bridge” (span : 120m, bearing dimensions : 3000 × 2800 × 150mm) in Figure 2.2. (d) .



(a) Sliding Bearing (BP-A Bearing)



(b) Pivot Sliding Bearing



(c) Pivot Bearing

(d) Tatsunokuchi Bridge Bearing photo

Figure 2.2. Steel Bearing

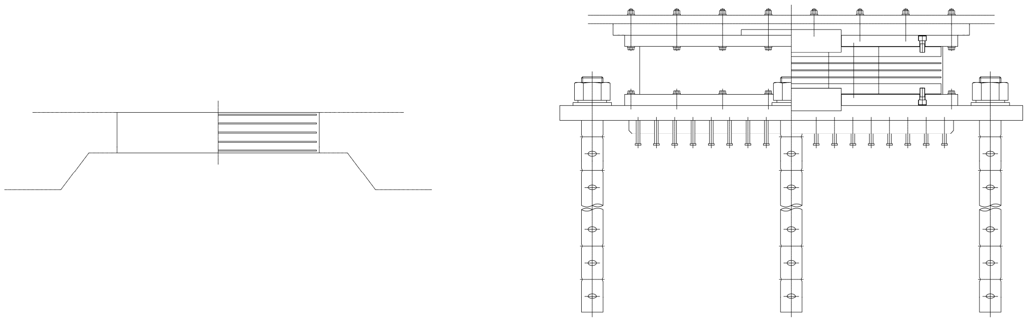
2.5. Pad Type Rubber Bearing

Figure 2.3. (a) shows the structure of the Pad Type Rubber Bearings. Rubber Bearing is vulcanized rubber and steel plate sandwiched alternately. In concrete railway bridge, this is half standardized and is very often used today. This bearing itself does not have a fixing member to the bridge and substructure, because it is a bearing that is expected to only support the vertical force and follow the movement. It must be used in pairs with another device to support the horizontal force such as stopper. As a rubber material, chloroprene rubber which has excellent weather resistance has been used since the early days. Currently in Japan, Pad Type Rubber Bearing is the most widely used bearing for concrete railway bridges, which ranges from 10m span small bridges to about 100m span large-scale bridges.

2.6. Lead Rubber Bearing, Rubber Bearing (for Seismic Isolation Bridge)

Rubber bearings are widely used in recent years for continuous girder bridge, which is designed for the purpose of easing the horizontal input ground motion using the soft spring. Figure 2.3.(b) shows the general structure. The structure of the rubber body is similar to that of the Pad Type Rubber Bearing mentioned earlier, and natural rubber is often adopted as the rubber material. While Pad Type Rubber Bearing only support the vertical force, Seismic Isolation Rubber Bearings need to support the horizontal force, so bolts and anchor bolts are placed to the bridge and substructure for fixation.

Lead Rubber Bearings is expected to specify long periodization as well as damping effects of pressurized lead plug. “Design Standards For Railway Structure and Commentary (Seismic Design)”[3) have been entry Lead Rubber Bearing (LRB) and High Damping Rubber Bearing (HDR). LRB is used in most railway bridges. However, in the current Design Standard adopted in Japan, the damping performance of Seismic Isolation Rubber Bearings is not recognized actively. In recent years, research has been done was for the purpose of adopting seismic isolation design railway bridges, expected to be used as means for minimizing the damage of the earthquake, as well as early disaster recovery.



(a) Pad Type Rubber bearing (b) Seismic Isolation Rubber Bearing (LRB)

Figure 2.3. Rubber Bearing

3. STOPPER USED IN THE RAILWAY BRIDGE

To have all the functionality that you expect is ideal, but bearing also has concerns such as the following:

1) Possibility of structure becoming complicated
2) Possibility of bearing dimensions becoming too large
3) Need for replacement when damaged

As how to resolve these concerns, the Japanese railway bridge used a design method called "functional separation" since the early days. In other words, supporting the vertical force, following the movement and rotation is the only expectancy during the standard state. The stopper is an important role member in terms of ensuring track. Here, we introduce stoppers that have been adopted in Japan.

3.1. Steel Bar Stopper

This is made by embedding steel bars in bridge and substructure, to support the horizontal force by the section. In general, this stopper is adopted to bridges smaller than about 15m. There is a distinction between fixed and movable, the movable stopper has a sheath tube which is designed to ensure the amount of movement.

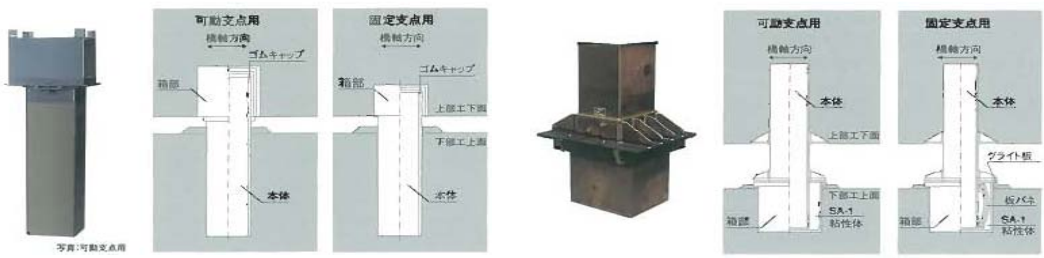
3.2. Steel Angle Stopper

Design concept is similar to Steel Bar Stopper mentioned before, in order to cope with even greater horizontal force, the body has adopted square steel pipe (JIS G 3466[4)). It has been adopted to bridges from 15m to about 50m, which Steel Bar Stopper can not cover. Figure 3.1. (a) shows the structure. The movable stopper has a box in order to ensure the amount of movement. The adoption of Steel

Angle Stopper is about 40 years ago, and since then, cost, workability and rust proof treatment have been improved.

3.3. Damper Stopper

Damper Stopper has a mechanism that allows fix-moved design while in standard state, and distribution (all fixed) design during earthquakes. So we are able to avoid designing fixed single substructure from simple supported girder bridges to continuous bridges. It has been adopted in about 100m span bridges. The adoption to large-scale bridges in recent years, for instance, “Sannaimaruyama Bridge” in Tohoku-Shinkansen, “Jintsu River Bridge” in Hokuriku-Shinkansen. Although the body uses square steel pipe similar to Steel Angle Stopper, placing the box in the substructure, and filling the gap between the body and box (Figure.3.1.) with viscous fluid. The viscous fluid is velocity dependent, resistance force of the bridge due to expansion is small, designed to generate the maximum resistance in fast motion, such as during an earthquake. So, as mentioned earlier, its mechanism that allows fix-moved design while in standard state, and distribution (all fixed) design during earthquakes is fulfilled. Viscous fluid is a state that is sealed by a sliding plate with a large stiffener which is placed on top of the box, the force of destruction by a large earthquake can be measured by leakage.



(a) Steel Angle Stopper (b) Damper Stopper

Figure 3.1. Stopper

3.4. Horizontal Bearing for Steel Bridge

Feature is similar to Steel Angle Stopper, the superstructure has a structure that can be signed by the bolt so that it can be attached to the steel girder. It has been adopted as the limit displacement in the perpendicular direction, it is used in conjunction with seismic isolation bearings. Usually it is used only between two Rubber Bearings, because of bridges having large horizontal force, it often becomes very large. Photo 3.1. indicates the installation status of the Tohoku-Shinkansen.

3.5. Cylinder-Type Damper

Cylinder-Type Damper has been adopted for the first time in “Oyachi Bridge”, in Hokkaido-Shinkansen (under construction). It is usually used as a damping device, but in this bridge it is used as a damper stopper. From the preceding, the damper stopper is a type embedded in the bridge and substructure, there is a need to install it during construction, Cylinder-Type Damper can be installed afterwards, often used in cases such as road bridges under earthquake-proof construction work.

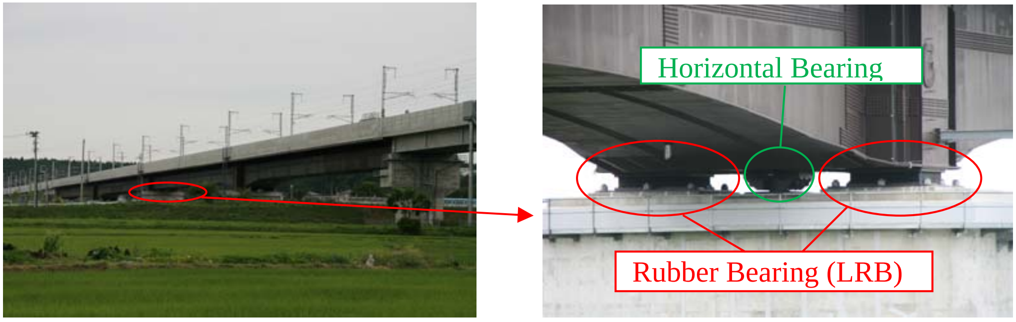


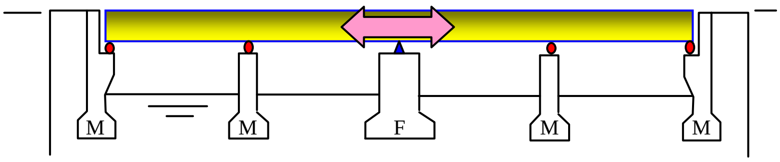
Photo 3.1. Horizontal Bearing and LRB (“Oirase River Bridge” in Tohoku-Shinkansen)

4. SEISMIC DESIGN OF BEARING PART IN THE RAILWAY BRIDGE

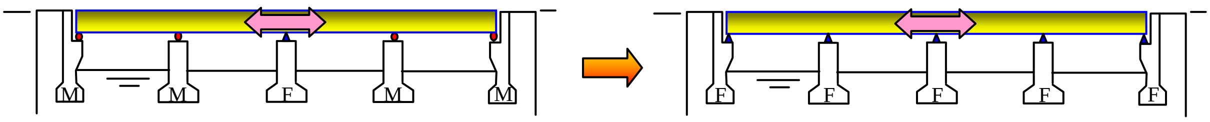
Seismic design of railway bridges in Japan is carried out according to the guide, “Design Standards For Railway Structure and Commentary (Seismic Design)”[3]. Classified into three stages of damage level, as shown in Table 4.1., designed the member to be equal to or less than the level of the structure of the ground motion, injury severity and frequency required by the scale.

Table 4.1. Damage level

	Damage level	The degree of repair
Damage level 1	Healthy state	No repair necessary
Damage level 2	Relatively minor damage bridge	Repair as necessary
Damage level 3	Some damage including the destruction of equipment or bridge displacement, but did not collapse	Repair or replacement is required



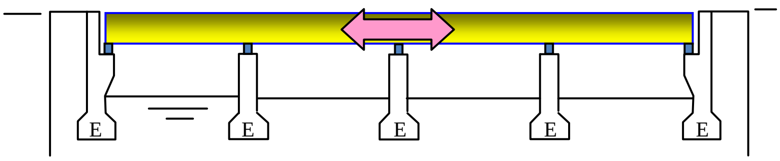
(a) Fix-Move



Standard State

Earthquake

(b) Distributing (Use Damper Stopper)



(c) Seismic Isolation (Use LRB)

Figure 4.1. Design Method

Design method of the bearing, as shown in Figure 4.1., may be divided into three types. We design according to the frequency of the earthquakes, bridges scale, and ground type. Distributed design of the Damper Stopper in particular is a technique-specific design in Japan. Railway bridges after being adopted from 1965, has experienced a number of particularly large-scale earthquakes, but none has be known to have collapsed by the earthquake.

5. DAMAGE CASES OF BEARING FOR "THE 2011 OFF THE PACIFIC COAST OF TOHOKU EARTHQUAKE"

The damage caused by the "THE 2011 OFF THE PACIFIC COAST OF TOHOKU EARTHQUAKE" and tsunami occurred on 11 March 2011, deprived many precious lives and destroyed many structures. There were many railway bridge affected, and we would like to introduce some of the bridges we have investigated. The Tohoku-Shinkansen between Iwate prefecture and Fukushima prefecture was heavily damaged. Structural damage has been confirmed due to relatively old design from the 1970s as shown in Table 1. Here we introduce some of the corruption of "THE 2011 OFF THE PACIFIC COAST OF TOHOKU EARTHQUAKE" along with the healthy railway bridge (Photo 5.1.), that was designed around the year 2004 using LRB (Photo 5.2.). Comparison cannot be unconditional because it is not the same place, but the manufacturing technology of the bearing and the current seismic design can be verified.

(a) Flexural Damage of Steel Bearing

Healthy

Damaged

(b) Destruction of the Roller Bearing (not the same bridge)

Photo 5.1. Disaster Situation of bearing (Tohoku-Shinkansen between Fukushima and Sendai)


Photo5.2. healthy status of the LRB and Horizontal Bearing (Sendai area)

6. CONCLUSION

We summarized the railway bridge bearing of Japan and the situation of the “THE 2011 OFF THE PACIFIC COAST OF TOHOKU EARTHQUAKE”. The probability of another large-scale earthquake occurring in Japan in the near future is high, the aim is to establish technology and to improve design from our experience.

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