In Japan, many rocking-pier steel railway bridges were built, mainly from the Meiji to the early Showa period. Fortunately, only a few of these bridges have been affected by earthquake damage. However, if damage is incurred by large-scale earthquakes, collapse is possible. Therefore, the seismic performance of these bridges was verified and reinforcement was implemented where necessary. For seismic diagnosis, the assessment is conducted on weaker sections, which are subsequently reinforced as necessary. This study introduces methods for seismic diagnosis and reinforcement.

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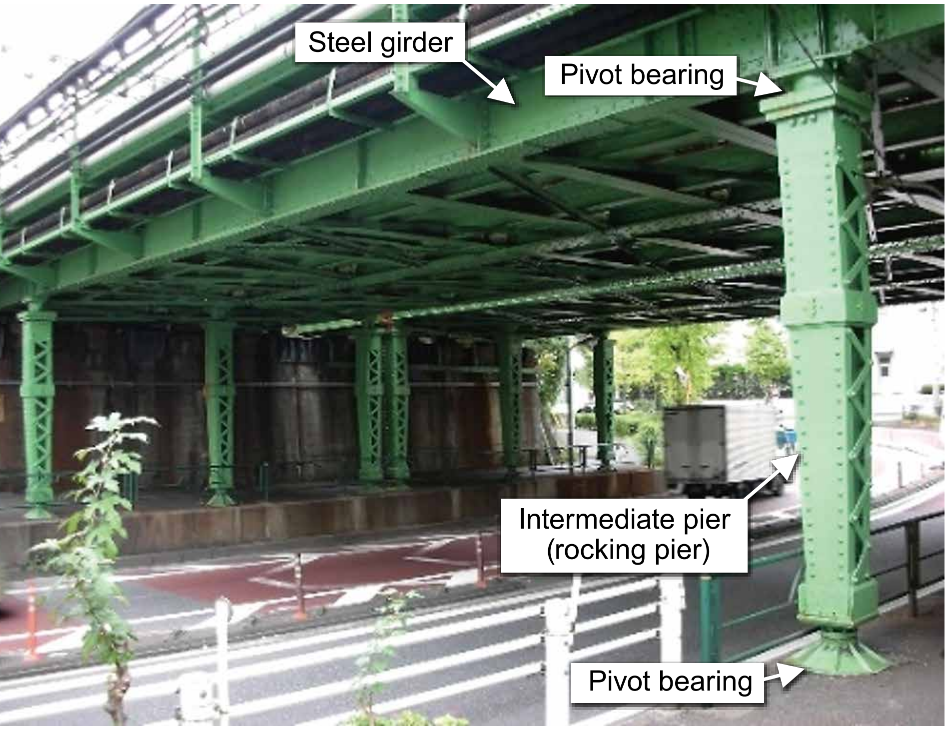
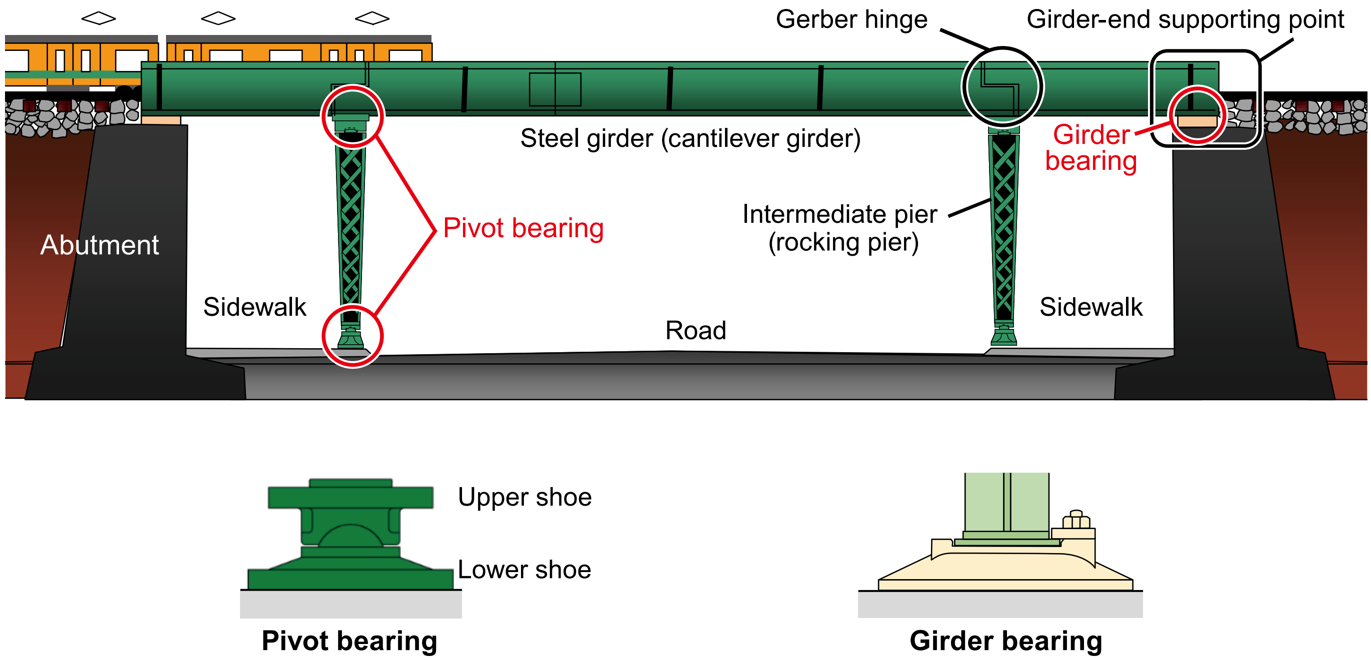
Seismic Diagnosis and Reinforcement of Steel Railway Bridges in Urban Areas



A bridge supported by rocking pier

Introduction

In urban areas, many railway lines were elevated, from the Meiji to the early Showa period. Along these lines, steel bridges were constructed at points where tracks passed over roads or other tracks. In sections where the line must pass over a wide road or a multiple-track railway line, a longer bridge is required. In such cases, bridge piers are constructed in the middle of the bridge (intermediate pier) and support the bridge girder, in addition to the abutment on both ends (*A bridge supported by rocking pier* and *Overview of a bridge supported by rocking pier*). "Rocking piers" with pivot bearings at the top and bottom are often used as intermediate piers to support longer bridges. The pivot bearings can rotate in all directions by combining sphere-



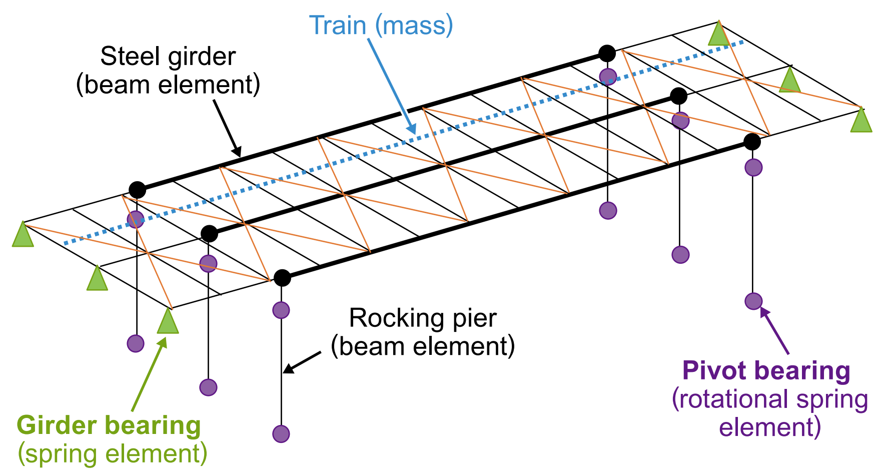
Overview of a bridge supported by rocking pier

shaped lower shoes and depressed upper shoes. Since rocking piers render bridges as statically determinate structures, the design calculations were conducted easily in the past even with the lack of well-developed computers.

When a rocking-pier bridge is shaken by an earthquake, only the supporting points at both ends of the bridge resist lateral force, but the rocking piers do not. Because of this property, once an earthquake occurs, the girder bearings are likely to be damaged, the girder is likely to move laterally, and it is possible that rocking piers might collapse causing the bridge to fall.

In the past, railway bridges did not suffer any serious damage due to earthquakes, such as collapse. However, in the Kumamoto Earthquake of 2016, one road bridge collapsed[1)]. Following this disaster, in 2018, rocking-pier bridges were included among the facilities to be regulated by the Government Order on Seismic Reinforcement of Specific Railway Facilities. Since then, seismic diagnosis has been prioritized, and seismic reinforcement has also been implemented depending on the results of the diagnosis.

This study describes seismic diagnosis and reinforcement methods for rocking-pier bridges.

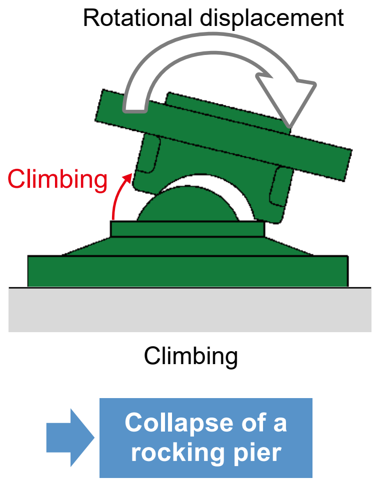


Analysis model

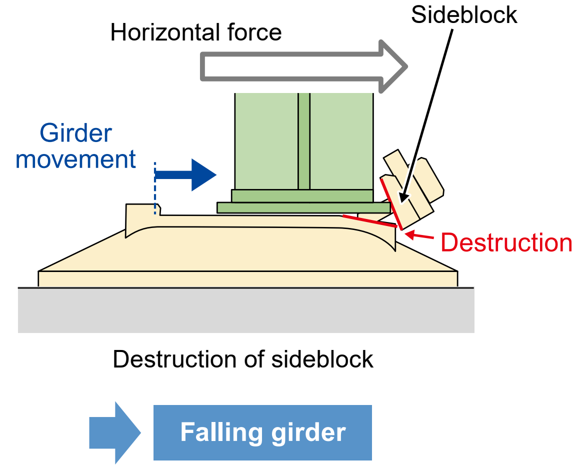
Seismic diagnosis method

In this study, for seismic diagnosis, a bridge is first modeled, as shown in *Analysis model* ; earthquake motion is then applied to the modeled bridge, and its impact is analyzed. Through the analysis, we investigated damage to pivot bearings, girder bearings at bridge ends, steel girders, rocking piers, and Gerber hinges.

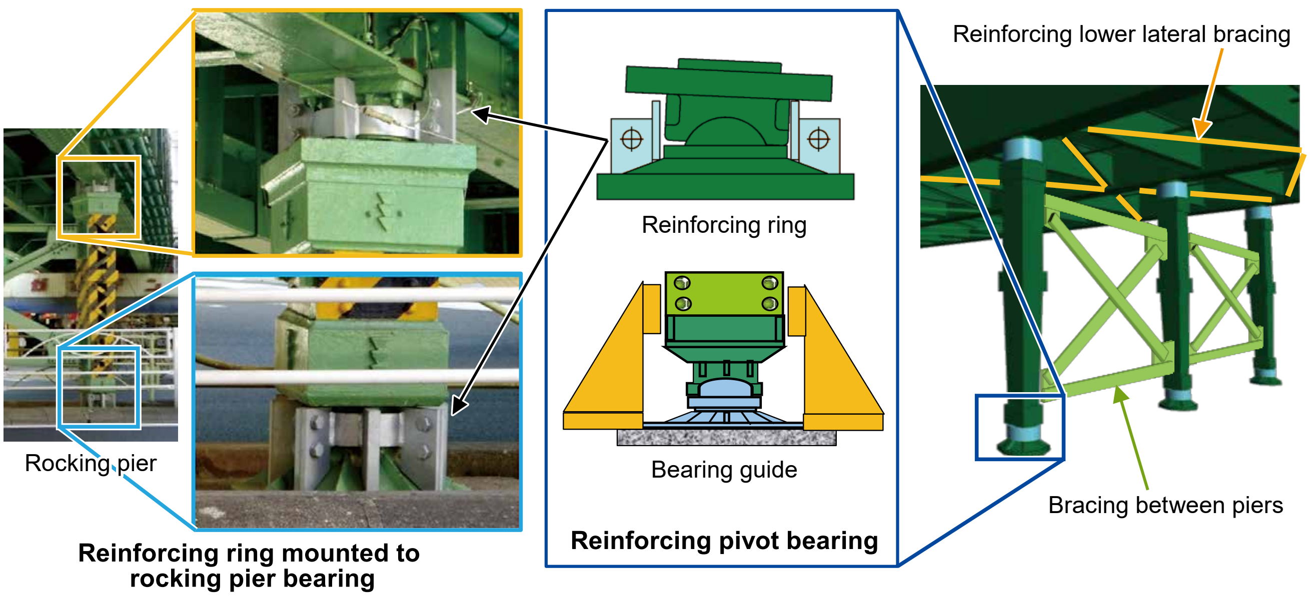
For the pivot bearing, we determined whether the upper shoe climbs up the lower shoe. As shown in *Climbing of pivot bearing* , when the displacement of the steel girder increases, the rocking pier tends to tilt, and the rotational displacement of the pivot bearing increases. Eventually, the upper shoe climbs up the lower shoe and



Climbing of pivot bearing



Destruction of girder bearing and girder movement



Prevention of rocking pier collapse

causes the collapse of the rocking pier.

For the girder bearing, as *Destruction of girder bearing and girder movement* indicates, we determined whether the side block that constrains the girder displacement is not destroyed by the lateral movement of the girder. Even if the side block is destroyed, the bridge is unlikely to collapse when the girder displacement is small, and the girder ends remain on the abutment.

Policy of seismic reinforcement

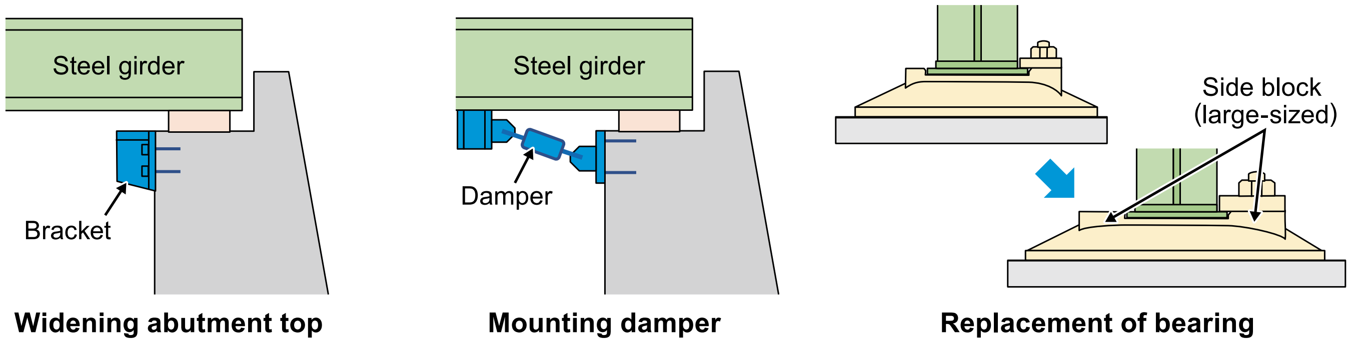
Since most rocking-pier bridges were built much earlier, they have not been designed to endure large-scale earthquakes. Therefore, through seismic diagnosis, some of the bridges were found to be susceptible to collapse if damaged by a large-scale earthquake hence the need for reinforcement.

The implementation of seismic reinforcement prevents collapse and enables early restart of train operations, depending on the importance of each line. We describe two seismic reinforcement measures: prevention of rocking-pier collapse and girder falling at the girder ends.

Prevention of rocking-pier collapse

By installing reinforcement rings or shoe guides on pivot bearings, the collapse of the rocking pier is prevented as shown in *Prevention of rocking pier collapse*.

Reinforcement rings prevent detachment



Measures to prevent girder falling at the girder-end supporting point

of the upper shoe of the pivot bearing from the lower shoe without losing ordinary rotating function[2]. Even if the upper shoe rises and comes off in an earthquake, the shoe guide prevents displacement of the bridge pier and guides it back to the normal position.

If this reinforcement is insufficient to prevent the collapse of the rocking pier, braces are installed between the piers. Alternatively, the lower lateral bracing of the steel girder is reinforced to reduce the lateral deflection of the steel girder and consequently reduced the rotating displacement of the pivot bearing.

Prevention of steel girder end support collapse

If there is a possibility that bearings at girder ends might be destroyed or a girder might fall from the abutment during an earthquake, the measures shown in *Measures to prevent girder falling at the girder-end supporting point* may be taken.

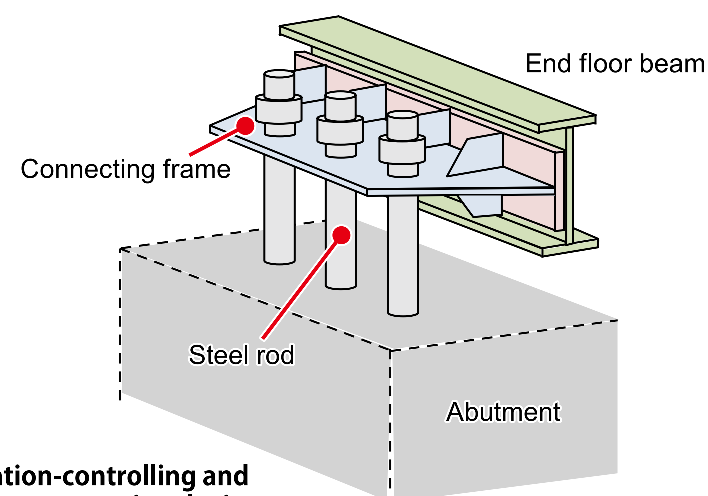
First, by mounting a bracket on the front side of the bridge abutment, the abutment top is widened and girder falling is prevented even if the bearing is destroyed and the girder is moved. Second, a damper absorbs the earthquake energy transmitted through the steel girder and controls the movement of the steel girder. Third, if the bearing is replaced by one with larger side blocks, it is less likely to be destroyed.

In urban areas, it might be difficult to ensure sufficient workspace or place to mount these devices, because bridges either have narrow abutment top spaces or under-bridge spaces are occupied by roads. However, because many urban railway lines are heavily used, minimizing the movement of the steel girder is a requirement to reinstate train operation as soon as possible after an earthquake. To meet these requirements, a new device to control vibrations and prevent bridge collapse has been developed[3].

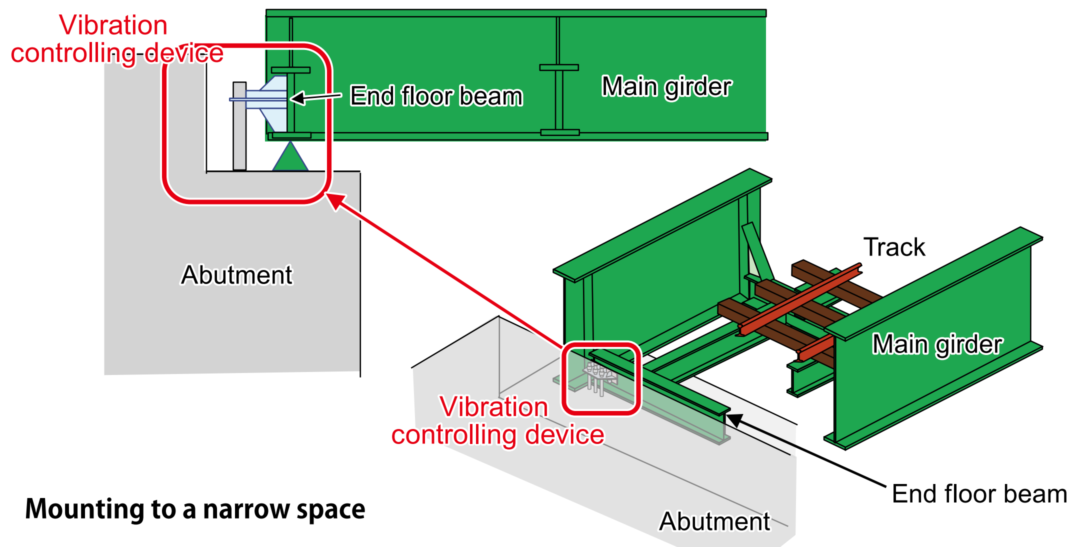
As shown in *Vibration-controlling and collapse prevention device* , the steel rods set up on the abutment are fixed on a steel frame and mounted onto the end of the steel girder. This device has the following two features:

First, since the steel rods absorb earthquake energy by deforming themselves and controlling the displacement of the steel girders, the earthquake damage is expected to recover early. Furthermore, as the steel rods extend, they are unlikely to be fractured by serious earthquake shaking, and the fall of the steel girder is likely to be avoided.

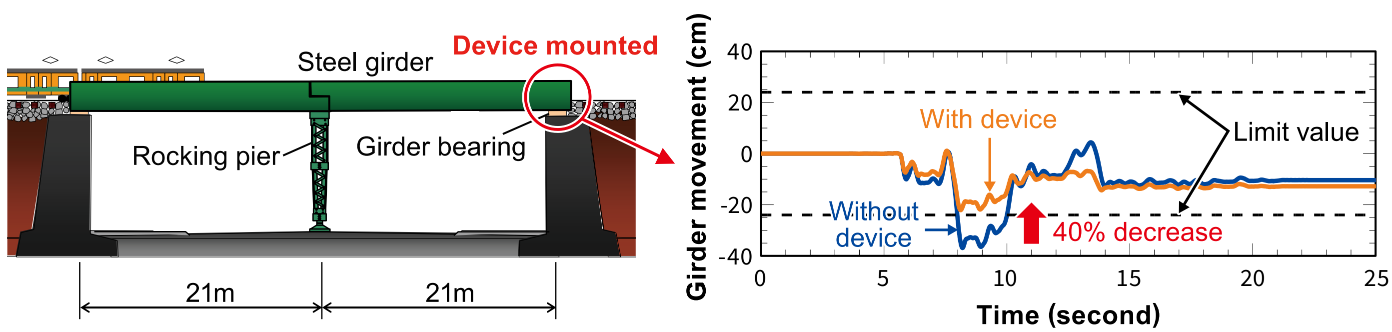
Second, owing to its small size, as shown in *Mounting to a narrow space* , this system can be mounted onto a narrow abutment top, and because it is placed on the abutment, it does not protrude into the undergirder space.



Vibration-controlling and collapse prevention device



Mounting to a narrow space



Verifying the effect by dynamic analysis

By analyzing the difference in the girder movement of two-span bridges mounted with this device, its effectiveness was validated. *Verifying the effect by dynamic analysis* compares the displacement of girders with or without the device when girder bearings at the bridge ends are destroyed by an earthquake. In this case, installing the device reduced girder displacement by 40%, from a maximum of 37 to 22 cm.

Conclusion

This study describes methods for seismic diagnosis and reinforcement of rocking-pier bridges in urban areas. It is important to identify weak sections by seismic diagnosis and implement measures that consider the balance of the entire structure and restraints in the construction and repair work. We will continue to develop seismic diagnosis methods that can be applied to different types of structures, and develop effective, low-cost reinforcement methods.

References

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