

# Seismic Reinforcement of Abutments and Retaining Walls in Narrow Space



**Mr. Kohei Kasahara**  
Assistant Senior Researcher,  
Foundation and Geotechnical Engineering,  
Structures Technology Division

Reinforcement of abutments and retaining walls to improve earthquake resistance involves major work at the front side of the structures. If the structure is located in a narrow space where land is limited, especially in urban areas, it is difficult to provide reinforcement. However, the structures in urban areas often require seismic reinforcement. Hence, it is necessary to develop cost-effective seismic reinforcement methods that can be implemented even in narrow spaces. This paper describes seismic reinforcement methods for abutment and retaining walls developed by RTRI that can minimize the workspace on the front side of structures during construction.

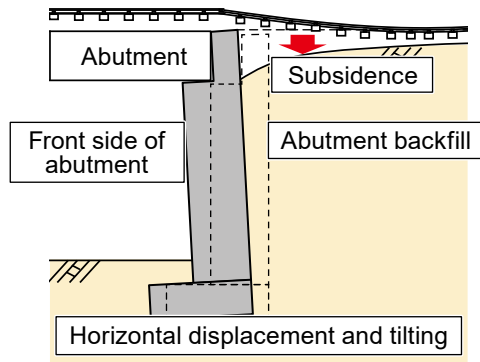
**A collapsed retaining wall  
(Great Hanshin Earthquake in 1995)<sup>1)</sup>**



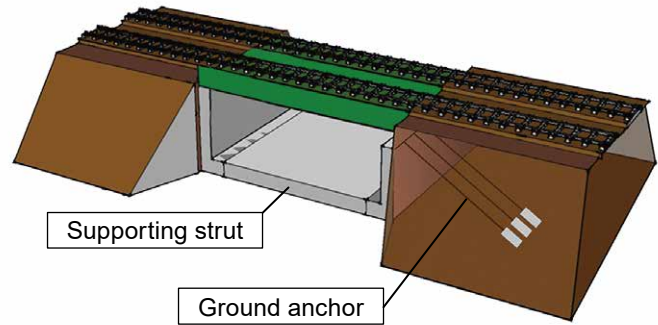
## Introduction

The abutments, retaining walls, bridges, and viaducts<sup>1)</sup> suffered serious damage during the Great Hanshin Earthquake in 1995 ( *A collapsed retaining wall (Great Hanshin Earthquake in 1995)*). After the disaster, the existing railway structures were reinforced to improve their seismic performance.

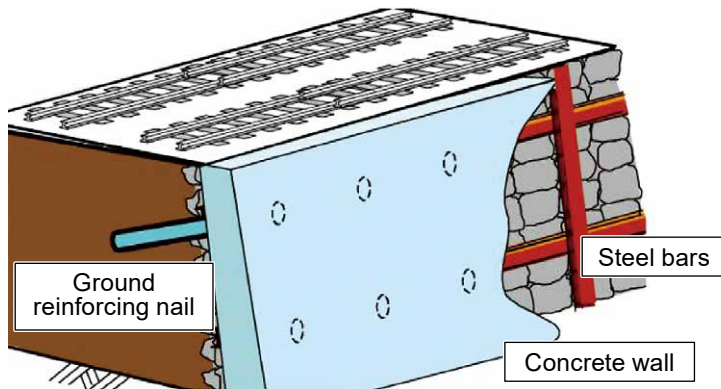
*Subsidence at the abutment backfill* depicts a case of damage to an abutment during an earthquake. In this case, the abutment was pushed by the embankment behind resulting in the abutment being laterally displaced or tilted; as a result, the embankment subsided. Railway structures damaged in this manner may lead to the deformation of tracks, seriously threatening the safety of trains running. Therefore, in recent years, seismic reinforcement plans have been implemented for existing abutments.



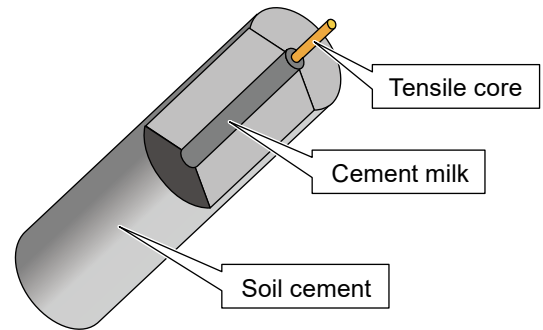
**Subsidence at the abutment backfill**



**Seismic reinforcement of an existing abutment <sup>2)</sup>**



**Seismic reinforcement of an existing retaining wall <sup>2)</sup>**



**Cross-section of ground reinforcing nail**

Meanwhile, there are more than 250 thousand retaining walls along railway lines across Japan, most of which are masonry walls. The masonry retaining walls were built before concrete walls became popular. However, several masonry walls have been reported to collapse during large earthquakes. It is necessary to develop low-cost methods for seismic reinforcement of a vast number of such retaining walls along railway lines.

### Existing methods

In the past, abutments were generally reinforced by supporting-strut and ground-anchor methods. In the supporting-strut method, a reinforced concrete slab is placed between the abutments to support them. The ground-anchor method uses high-strength steel tension rods to fix abutments to the ground (*Seismic reinforcement of an existing abutment*). To reinforce retaining walls, in many

cases, concrete walls were built on the front side of the retaining walls, as shown in *Seismic reinforcement of an existing retaining wall*, and ground reinforcing nails in *Cross-section of ground reinforcing nail* were placed to ensure the stability of the concrete walls.

However, these methods require a wide workspace in front of the structures. Therefore, these methods making it difficult to implement them in narrow places where there are roads or tracks in front of abutments or retaining walls. However, because most structures to be given priority in reinforcement are in urban areas where they are often confined to narrow spaces, a reinforcement method that is inexpensive and can be implemented in such spaces is to be developed.

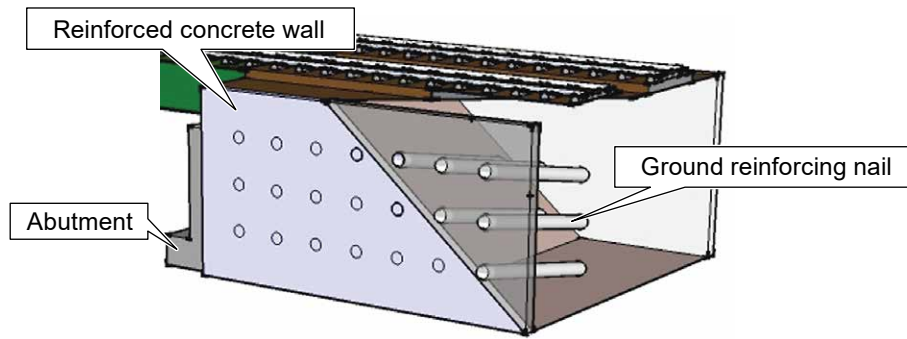
This paper explains seismic reinforcement methods for abutments and retaining walls, that can be implemented even in narrow workspaces in front side of the structures, has been presented.

### Seismic reinforcement methods for the abutment

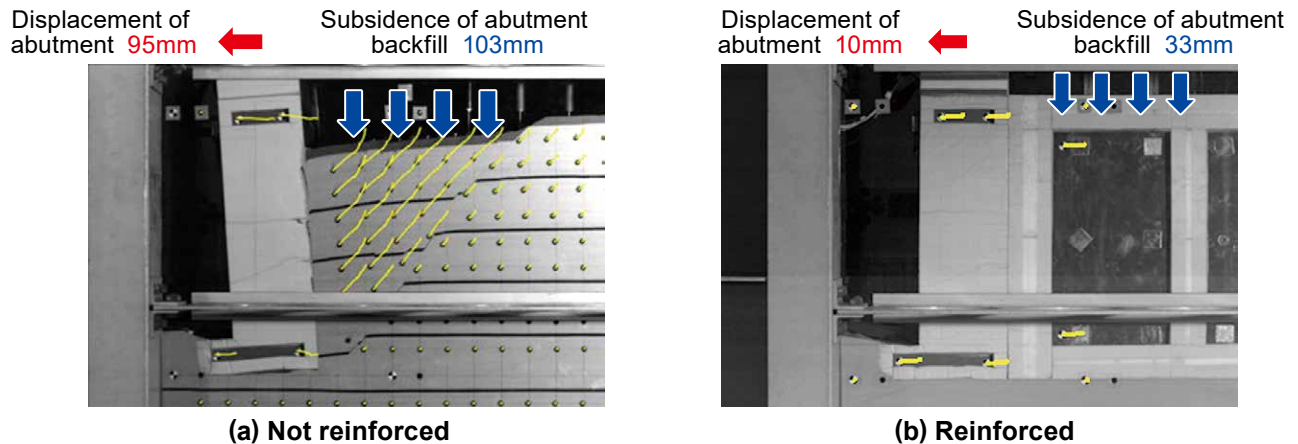
#### (1) Integrating ground-reinforcing nails and abutment

In this method, construction begins from the backside of embankment of the abutment (*Seismic reinforcement by integrating ground reinforcing nails and abutment*). By integrating the abutment, concrete wall, and ground reinforcing nails, the earthquake resistance of the abutment is improved, and it is less likely to collapse, even when hit by a severe earthquake. This method is adopted to reinforce the spots where the earthquake resistance of the wing walls (retaining wall built adjacent to the abutment) is insufficient, and the abutment backfill is likely to flow out through the gap between the wing walls and abutment in the case of an earthquake.

A model shaking experiment to confirm the reinforcing effects is briefly introduced herein. In the experiment, a



### Seismic reinforcement by integrating ground reinforcing nails and abutment<sup>2)</sup>



### Performance test for seismic reinforcement of abutment<sup>2)</sup> (Integrating ground reinforcing nails and abutment)

1/8-scale abutment model was shaken by a simulated earthquake on medium-sized shaking machine of the RTRI (*Performance test for seismic reinforcement of abutment (Integrating ground reinforcing nails and abutment)*). The results confirmed that the residual displacement (final displacement amount of the abutment after shaking) and subsidence on the abutment backfill were significantly reduced due to reinforcement. The application of this method to actual structures is currently being planned. The structures to be reinforced are bridges over railway tracks and their embankments.

#### (2) Soil-improvement of abutment backfill

In this method, soil cement columns are placed in the abutment backfill. These columns restrict abutment deformation and backfill subsidence<sup>2),3)</sup> (*Seismic*

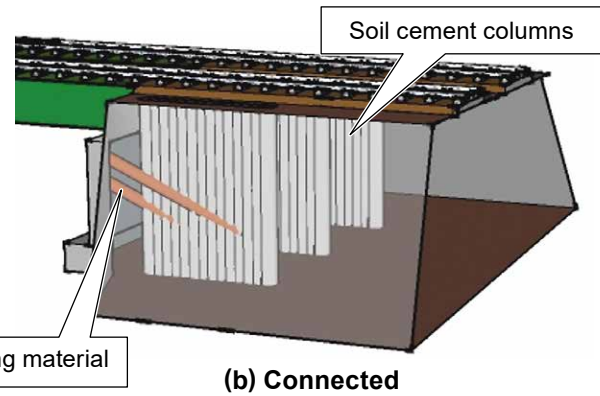
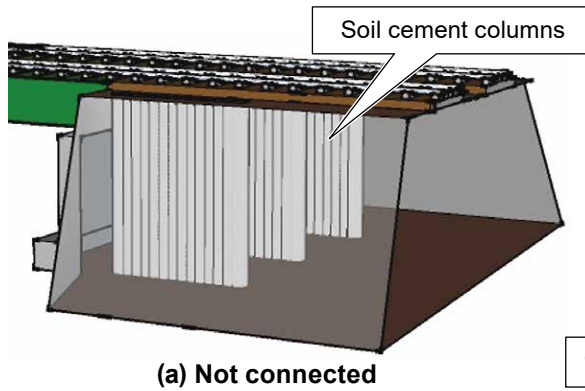
*reinforcement by soil-improvement of abutment backfill (a)*). This method is applied mostly to abutment backfill that are built with low-quality materials. Because soil cement columns are placed from the track face (top of the abutment backfill), workspace at the front side of the abutment is not required. Columns can be placed using low-height machinery that does not reach the overhead lines. Furthermore, if the abutment does not have sufficient earthquake resistance and is likely to collapse by overturning in an earthquake, it can be reinforced by connecting the abutment with columns using connecting material (PC steel rods inserted and fixed with mortar) (*Seismic reinforcement by soil-improvement of abutment backfill (b)*). Such cases require workspace in front side of the abutment.

Model shaking experiments have

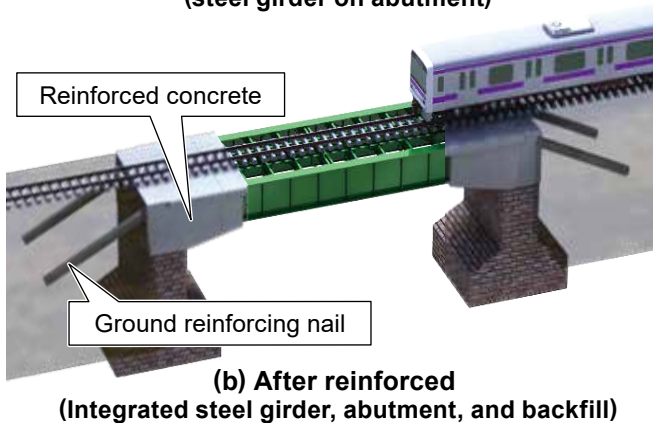
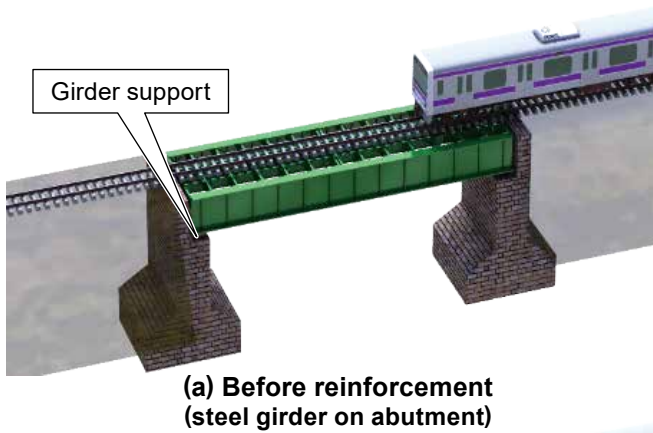
confirmed that the seismic resistance of the abutment is improved by this type of reinforcement. Furthermore, by connecting the abutment and soil cement columns, the effect of suppressing the abutment collapse by overturning was demonstrated, which indicates that the seismic resistance was significantly improved. This method has already been used to reinforce abutments of an actual railway line<sup>3)</sup>. Here, only one row of columns was placed on each side of the track, but two were built at the location where there is a wide space between tracks on a double track.

#### (3) Integrating steel girder-abutment-backfill

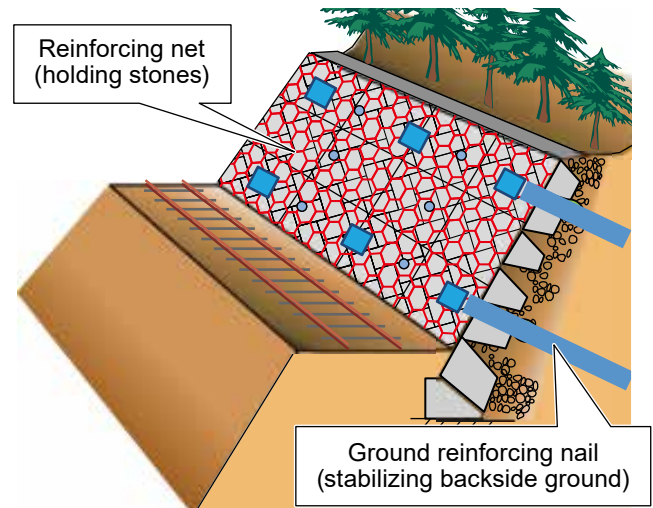
This method integrates steel girders, abutments, and the abutment backfill with reinforced concrete and ground-reinforcing nails to extend the service life



**Seismic reinforcement by soil-improvement of abutment backfill<sup>2)</sup>**



**Integrating steel girder, abutment and backfill<sup>2)</sup>**



**Net-reinforcement method<sup>2)</sup>**

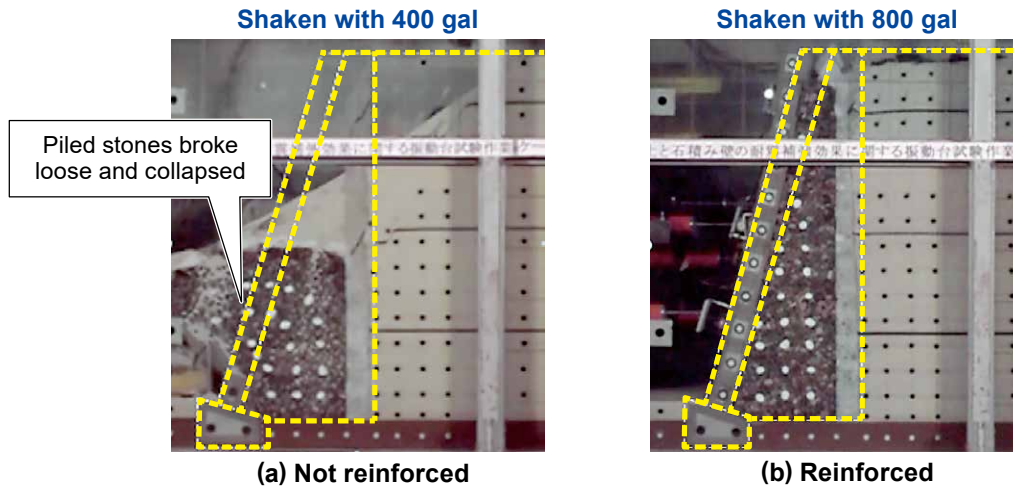
and improve the earthquake resistance of old bridges (*Integrating steel girder, abutment and embankment*). As the intersection (including bearings) of the steel girder and abutment is covered with concrete, it reduces maintenance, and the integrated girder and abutment prevent the falling of the girder. Furthermore, by

connecting the abutment and backfill with reinforcing nails inserted from the side or front of the abutment, subsidence of the backfill is prevented making the abutment more stable. Because this method is likely to improve earthquake resistance by changing the structure, it is effective in enhancing the seismic performance of

steel girders with deteriorated materials or abutments made of bricks and piled stones.

To study the efficiency of this method, model experiments were conducted to investigate the reinforcement of intersection of the girder and abutment. Based on these experiments, basic characteristics such as behavior during an earthquake was confirmed. In addition, a test-purpose bridge was constructed and its performance was verified by continuous observation and loading tests.

This method has been applied to reinforce an actual structure<sup>4)</sup>. Initially, the plan was to replace the bridge. However, by adopting this method, the earthquake resistance of the bridge was improved, and



**Performance test for Net-reinforcement method<sup>2)</sup>  
(Yellow broken line indicates the position of retaining wall before shaking)**

its service life was extended at a reasonable cost. Through a performance check, it was confirmed that the girder flexure was reduced to 1/2 to 1/3 of the pre-reinforcement, and the noise level during the passing of the train was also lowered.

### Seismic reinforcement method for the retaining wall

A reinforcing method called the net reinforcement method has been proposed for the retaining walls in narrow spaces. In this method, the front side of the masonry retaining wall is covered with a wire net to hold piled stones, and ground-reinforcing nails are placed to stabilize the trackside slope (*Net-reinforcement method*). When reinforcing retaining walls with this method, it is not necessary to move obstacles, such as cables, on the front face of the wall or to build concrete forms. Therefore, reinforcement work can be conducted in a narrow space such as a railway track that is laid right in front of a wall.

The effects of the net reinforcement method were confirmed in the model shaking experiments. The experimental results are shown in *Performance test for Net-reinforcement method* (Yellow broken line indicates the position of retaining

*wall before shaking*). After the model retaining wall without any reinforcement was shaken with an acceleration of 400 gal, the piled stones broke loose, and the wall collapsed. However, the model retaining wall reinforced with this method was only slightly deformed even after being shaken intensely with an acceleration of 800 gal. These experiments prove that the retaining wall reinforced with this method can withstand a large earthquake.

The net reinforcement method has already been applied to an actual retaining wall. It is a 7-meter-high masonry retaining wall, and cables are laid at every corner

of the surface. Because it is difficult to remove the cables and cover the wall with concrete, the net reinforcement method was adopted, and the cables were left on the wall.

### Conclusion

This paper introduced seismic reinforcement methods available for abutments and retaining walls located in narrow spaces. We will collect and analyze cases of reinforcement to further improve the reinforcement methods, and propose methods to choose the best measure.

### References

- 1) Earthquake Measure Project of the Railway Technical Research Institute: "Report of Investigation of the Railway Damage by the 1995 Great Hanshin Earthquake", RTRI Report Special Edition, 1996
- 2) Taisuke Sanagawa, Susumu Nakajima, Masayuki Koda: "Seismic Reinforcement Method for Abutment and Retaining wall Available under Strict Conditions", RTRI Report Vol.34, No.6, pp.11-16, 2020
- 3) Satoshi Takizawa, Hiroshi Nakamura, Akihiro Yutani, Hideaki Takasaki, Hirofumi Ikemoto, Tadashi Yamamoto: "A Case of Technical Development Result Applied to Actual Seismic Reinforcement of Earth Structure", SED, No.53, pp.38-46, 2019
- 4) Yuma Hayakawa, Shunsuke Okino, Taisuke Sanagawa: "Seismic Reinforcement of Former Ondagawa Bridge of Odakyu Odawara Line – A Method to Integrate Existing Embankment and Bridge –", the Journal of JGS, No.4, pp.27-30, 2021