Development of the Renewal Technology for the Railway Structures

Summary

Railways in Japan have developed through extensive construction and improvement since the Meiji Era. Many structures have been constructed during the period; however, repair and reinforcement has become required in an increasing number of cases because the aged structures are increased. In addition, it is also required to cope with new requirements such as countermeasures against earthquakes and improvement in comfortability and convenience, which were not expected at the time of construction. As a measure for the situation, we have developed technologies for extensive renewal of the existing structures. This article introduces those technologies.

1. Introduction

More than 140 years have passed since the first railway was inaugurated in Japan in 1872. 50 years has passed since the inauguration of the Tokaido Shinkansen in 1964. Many structures have been constructed to expand the railway lines during the period. Recently, because the aged structures are increasing in number, the maintenance and management of these structures have become an important problem. Railways are one of the essential life lines and their functionality is not allowed to, even temporarily, be hindered due to replacement of a structure; therefore it is basically required to keep using the existing structures as much as possible.

Based on the above, RTRI has been working on the innovation of renewal technology for railway structures for 5 years since 2010 as one of its challenges related to research and development for the development of railways in the future. We have developed technologies for spatial creation in a station and improvement of comfortability as well as life extension for existing structures to allow safe use for a long time, and for improvement of earthquake resistance against large-scale earthquakes, which are expected to occur in the future. We introduce a part of the development results in this article.

2. Renewal technology for viaduct

The beam-slab rigid frame structure made by reinforced concrete (hereinafter referred to as "RC") that is widely used for railway viaducts consists of members such as the column, beam, and slab (floor deck). For renewal of the viaducts, we developed repair and reinforcement technologies for each member within the structure.

(1) Repair and reinforcing method for beam and slab

Construction for RC rigid frame viaducts started in the beginning of Showa Era and then became widely used for grade separations and Shinkansen lines. Some of the huge number of viaducts that were constructed during the high growth period have deteriorated relatively earlier after their construction, and corrosion of the reinforcing bar and/or spalling of concrete occurs in them.

The beam and slab of the beam-slab RC rigid frame viaduct are integrated in one unit and composed of the longitudinal beam (in the direction of the rail), lateral beam (in the direction perpendicular to the rail), intermediate slab that is enclosed with the aforementioned beams, and cantilever slab that is overhung to the outside of the longitudinal beam. Among these components, the intermediate slab of the viaduct is an important member located directly under the track. In some cases, the load carrying capacity of the slab will be reduced due to corrosion of the reinforcing bar is concerned, and it is required to reduce the noise and vibration when a train runs over it. To solve these problems, we developed a repair and reinforcing method for the intermediate slab using an ultra high strength fiber reinforced concrete (hereinafter referred to as "UFC") board. This method installs a UFC board that has high durability and is also expected to have tensile strength and rigidity under the slab and fills shrinkage-compensating mortar to integrate the board with the slab (Figure 1). Because the board is thin and light-weight, the load on the foundation does not increase so much. In addition, the workability is improved because the method does not require a large scale scaffolding compared to the conventional full-sectional repair method. It is expected that the load carrying capacity is significantly improved with the method.

For the reinforcing effect, we conducted a load test to verify that the load carrying capacity is significantly improved. In addition, it is expected that the vibration and noise can be reduced because the rigidity of the slab is improved by approximately 5 times. We also

![Fig.1 Repair and reinforcing method of viaduct slab]
analyzed to verify that the noise emitted from the structure when a train runs on it decreased by 3.4 dB (overall value).

On the other hand, the cantilever slab is a component that supports the handrail and noise barrier installed on the edge of the slab. When raising the noise barrier to improve the noise reduction effect, the load carrying capacity of the slab can become insufficient. To solve the problem, we developed a reinforcing method to add small beams on the lower surface of the cantilever slab. Thanks to the method, the handrail can be raised by approximately 5 meters on the slab.

For the beam and the handrail of viaduct, we developed a reinforcing method that uses arch-shaped steel plates and relocating the column without any large-scale temporary work. It has become possible to renew the members such as the beam and slab in a viaduct in full-scale by combining these methods.

(2) Technology for replacement / relocation of column

The column of the viaduct is an important member that controls the earthquake resistance and various aseismic reinforcing methods that have been developed so far. On the other hand, recently there is increasing demand for effectively using the space under a viaduct for various facilities. Sometimes the use of the space under a viaduct is restricted due to the locations of the columns and it is required to replace and relocate the columns to solve the problem. However, it is required to conduct a large-scale work to replace the column of a viaduct in the conventional method.

To solve the problem, we developed a method for replacing and relocating the column without any large-scale temporary construction using a concrete-filled steel tube (hereinafter referred to as "CFT"). The CFT column is composed by filling concrete in a steel pipe, and provides high load carrying capacity with a relatively small cross section compared to other types of components. This method can be applied to the replacement or relocation of a column in various conditions. It allows to expand the interval between the columns by installing the CFT column between the existing columns and then removing them (Figure 2).

This method features use of the CFT column and it is required to develop a method to install the CFT column by connecting it to the existing RC beam.

We developed a new connection method that bores holes on the side of the RC beam, inserts the through steel rods into the holes after installing the steel reinforcement member so that it wraps the beam, and then fills the gap with grout material as shown in Figure 2 (right). The steel reinforcement member is structured to be integrated with the steel pipe of the CFT column to allow to transfer the load between the beam and the column. This method does not require to remove the concrete of the existing beam largely and allows to improve the efficiency of the works. In addition, because the steel pipe of the CFT column can be used as a temporary supporting column even before filling concrete, the installation of temporary construction can be significantly eliminated.

As described above, this method allows not only to implement measures against aged deterioration and earthquakes by replacing the viaduct columns, but also to effectively use the space under a viaduct by relocating the columns. Although in some cases it is required to reinforce other parts of the viaduct in addition to the columns because of the specifications of the viaduct or new location of the relocated column, it can be coped with by foundation reinforcement by using additional piles and the beam reinforcement mentioned above.

3. Renewal technology for steel bridge

A huge number of steel bridges have been constructed since the Meiji Era. However, recently the cases in which it is adopted as a new structure have decreased because of the problems it causes such as noise. Therefore many of the existing steel bridges are located in lines that were constructed before WW2. For most of them, a long time has passed since the construction and some of them have been used for more than 100 years.

In some of the aged bridges, various problems occur, such as disorder in the bearing component, decrease of the load carrying capacity due to corrosion, subsidence of the backfill of the abutment during earthquakes, and noise and vibration caused by the train running on the bridge. Therefore, measures such as reinforcement and/or replacement are required for these bridges.

To solve the problem, as a countermeasure against the insufficient bearing capacity due to corrosion in the existing steel girder and noise caused by trains running on the bridge, we developed a "composite structure method" that installs a precast floor deck instead of bridge ties and integrates it with the existing steel girder via the shear connector. The method is verified to provide a load carrying capacity of 1.2 - 1.5 times that of the steel girder and significantly decrease the stress generated in the steel girder. For this method, other effects such as prevention of local corrosion in the upper flange can also be expected in addition to the improvement in the load carrying capacity and fatigue resistance. Furthermore, as a secondary effect, noise is significantly decreased because the structure is changed from an open deck system to a closed deck system.

In addition, we developed an integration of existing steel girder, abutments and embankments that eliminates the bearings of the steel bridge to integrate the steel girder and the abutments, and integrates the abutments and the embankments in the back of them (backfill) by using ground reinforcing material (Soil nailing) to rehabilitate the functionality of the bridge without replacing the steel girder (Figure 3). The bending moment in the central part of the girder of the existing bridge before the reinforcement is large because the bridge is a simple beam structure; however, the bending moment decreases to half because the bridge is converted to a rigid frame load structure. The life can be extended by decreasing the sectional force as mentioned above, even for the steel girder of which the load bearing capacity has deteriorated due to corrosion.

According to the result of the construction experiment conducted by using the full-scale experiment bridge in the embankment test field of RTRI, it was verified that the structure implemented by this method had a high earthquake resistance because the displacement in the abutment caused by the horizontal force corresponding to an large-scale earthquake was approximately 10 mm and so small, and the damage on the bridge members was also minute.
4. Technology for station space renewal

(1) Renewal of the space of underground station

In underground stations in urban areas, for congestion mitigation and functionality improvement, an increasing number of works are conducted to widen the space of existing tunnels by making an opening on their walls and connecting with the space of a new tunnel structure. However, huge reinforcements are required in some cases because the large opening made on the wall affects the bearing capacity of the existing tunnel that is actually used. To solve the problem, we developed a method to connect existing and new tunnels while controlling the impact of the opening on the existing tunnel.

This method installs a reversed beam so that it holds the upper deck of the existing tunnel and connects the new and existing tunnels together with the horizontal and vertical anchors installed crisscross (Figure 4). The structure implemented by this method not only integrates the new and existing tunnels in the direction across the track but also suppresses the increase of the load on the existing tunnel due to the opening by installing the reversed beam in the direction of the track to spread the load. We conducted a load test using a full-scale model to verify that the new and existing tunnels move in one united body and the connected part has a sufficient bearing capacity. In addition, we developed a practical design method of the structure.

![Fig.4 Large-scale renewal method for underground stations](image)

The result of a test calculation for a case in which an opening 12 m wide is made in a standard 2-span underground station with 2 layers indicates that this method can reduce the reinforcement required for the existing tunnel and the cost can be cut by approximately 10% compared to the conventional method.

(2) Renewal of the space of aboveground station

Because the platform of an elevated station is directly exposed to the outdoor environment, it cannot necessarily be a comfortable space under certain weather conditions. To solve the problem, we developed a method to make the platform a shelter to improve comfortability (Figure 5).

By making the platform a shelter, many benefits can be expected, such as prevention of passengers falling from the platform, expansion of space that can be used because the walls of a waiting room can be eliminated, and covering the platform against rain and wind. On the other hand, some disadvantages such as decrease of illumination and temperature rise in summer seasons are expected to occur. In addition, unlike the case when newly constructing all the structures including the viaduct, it can be difficult to make an existing station a shelter because the load on the existing viaduct increases because the weight of the wall and platform screen doors is added.

Therefore this method adopts a membrane material (that consists of glass fiber coated by fluoroplastic or alike and is verified to have a designated strength as a construction material) to reduce the weight. The roof of existing stations is constructed with material such as steel plates so as to be extended over the track to prevent rain from entering the platform. In this method, because the roof is replaced with that made of the membrane material and the walls function as protection against rain, the area covered by the roof can be limited to that directly above the platform. Therefore the method significantly reduces the weight of the roof and allows installation on the existing viaduct. In addition, the method can also mitigate the decrease of illumination that is a problem when making the platform a shelter because the membrane material is permeable to sunlight.

On the other hand, it is required to provide an opening to secure sufficient ventilation to prevent conditions from becoming worse due to hot weather in the summer season. Considering the above, we determined the amount of opening required to prevent the temperature on the platform from rising too much compared to the outside temperature based on the result of model experiments.

5. Conclusion

We consider that the technologies we developed for renewal of structures contribute toward maintenance cost reduction, securing safety, and improvement of comfortability. We want to develop a design tool to promote the technologies in the future.

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[References]