Interpretive Article

Reduction of the Cost of Construction in the Space Above and Below Rails

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In order to newly create space above and below railway tracks, the construction work must be carried out without impairing the operation of vehicles and human traffic, and impediments such as railway tracks and underground cables have to be avoided. Keeping the increased costs in check under these limiting conditions is an issue of some significance. Towards this end of reducing the cost of construction, JR East Railway Company has developed technology for carrying out construction in such restricted space as the space between railway tracks and technology for 'rapid' construction to be completed in the late hours of the night when trains are normally not running.

1 Introduction

The space above and below railway tracks, and in particular, the space above and below railway tracks at stations is used for the flow of people and meeting of passengers and is extremely important as a link to the community. The development of such space will provide new services such as improved flow of people and new stores that are convenient for passengers and may be expected to invigorate the community.

Figure 1 shows the construction of an enormous artificial foundation called Federation Square that opened in December 2002 in the vicinity of Flinders Street Station in Melbourne, Australia. Even in Australia with its vast wide-open expanses of land, stations and their vicinity offer the appeal of attracting people. And even though the construction cost would be higher than on ordinary land, an artificial foundation was constructed above about 10 railway track routes.

Fig.1: Construction of an Artificial Foundation in Australia

This type of appealing space faces the issue of cost when construction is considered. Compared to normal construction and civil engineering work, increased costs arise from the facts that the right of way of trains cannot be limited and human traffic cannot be impaired, while at the same time safety must always be assured. Normally, the main work involved in the driving of piles and construction of columns and girders in metropolitan areas must be completed within a period of about two hours during the night when trains are normally not running after having taken the proper procedures for closing the railway tracks and shutting down the supply of electric power.

2 Target for Cost Reduction

When considering costs using the construction of the artificial foundation as an example, there are numerous impediments such as train lines, tracks, and underground cables as can be seen in Figure 2. The time during which work may be performed is limited, as are the positions where columns may be constructed and there are also the limitations of budget and building height. Today, when constructing an artificial foundation at a station in the metropolitan district in the space above the tracks, the construction cost per unit area is about five times that of construction on a normal graded foundation. While the individual conditions surrounding construction differ according to the location and depending on the approach and status of impediments, the objective is to develop construction technology that will reduce this cost-difference to a factor of 2 to 2.5 times the construction cost on ordinary land.

In the following sections, major technical developments that have been undertaken by JR East Railway Company will be introduced.

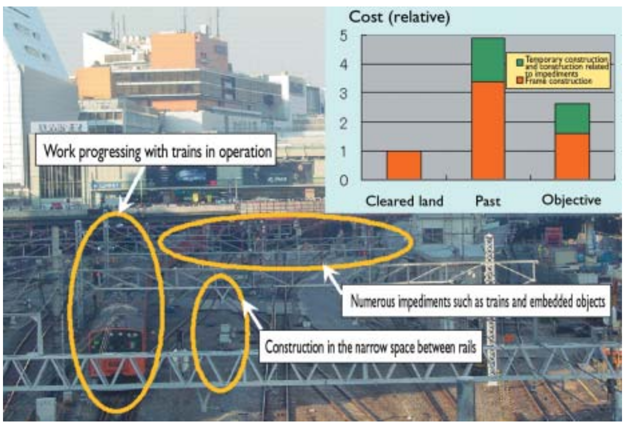

Fig.2: Impediments Above Tracks and Cost Objectives

3 Technical Development towards Reduction of the Cost of Construction of Artificial Foundations

With respect to the construction of artificial foundations, the construction methods that we have developed are mainly methods of reducing the work of excavation in the space between tracks and driving piles.

3.1 Eliminating the Underground Girders

Up until now, in order to preserve the hardness and resistance of the artificial foundation, underground girders were installed in the direction of the track as shown in Figure 3 (a). In general, the system of underground girders which are effective in terms of the safety of the structure have been prone to causing disturbances and divergences to the railway tracks and had other significant limitations such as time, resulting in installation costs that are significantly higher than in the case of other methods.

For this reason, in order to enable a structure that does away with underground girders in both directions, as shown in Figure 3 (b), analysis and verification of safety were conducted. With respect to standards, the "Structural Design Standards for Structures (Low Level) above Tracks" was amended through the cooperation of railway companies and with the Railway Technology Research Institute acting as general manager (Note 1). When the structure does away with the underground girders in both directions, the performance of the underground girders that had been used in the past must be dispersed and in order to curb divergence, there are cases in which the columns are made larger, but the total cost of the structure may be reduced by approximately 10%.

In principle, in the artificial foundations constructed at Tsudanuma Station, Omiya Station, Nishifunabashi Station, and others, the method that eliminates the underground girders in the two directions has been used since 2001.

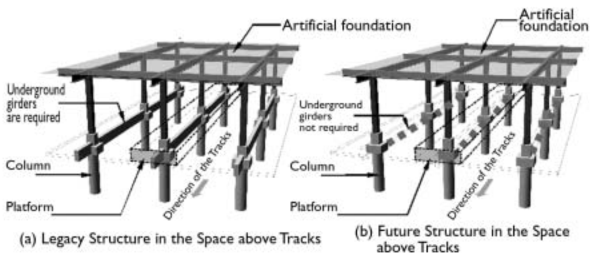

Fig.3: Structural System without Underground Girders

3.2 Connecting the Pile and Column Socket

The connection between the pile and the column normally uses a part that is called an anchor frame as shown in Figure 4 (a) and a footing is installed in order to ensure the dissipation of force between the pile and the column. In constructing such a structure in the limited space between tracks, it becomes necessary to excavate the roadbed over a wide section, and as time is required for such installation, this leads to increased costs.

For this reason, a system of connection was developed whereby a small diameter steel pipe is inserted into a large diameter steel pipe that forms a single unit with the pile to a given depth, and concrete is poured to fill the gap as shown in Figure 4 (b). Prototype tests were conducted with respect to this connection structure which is normally called a socket joint in order to determine the load resistance capacity of the connection and the ultimate strength. Based on the results of this test, a simple and generally usable method of ultimate strength evaluation has been proposed (Note 2). This socket joint was jointly developed together with Nippon Steel Corporation.

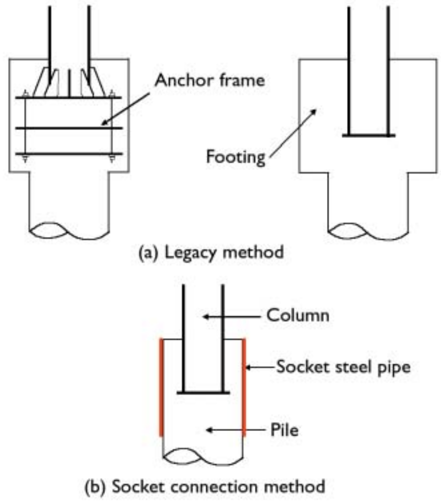

Fig.4: Pile Head Socket Connection

In the construction work at Kitasenju Station where two levels of artificial foundations for a concourse above the Joban Line and platform and the Tsukuba Express track floor are being constructed using the socket method, despite the proximity to the tracks, it was possible to form a connection between the pile and the column in an economic manner. In other initiatives, the extension of the width of the free walkways at Kashiwa Station and Musashi Urawa Station also utilize this method.

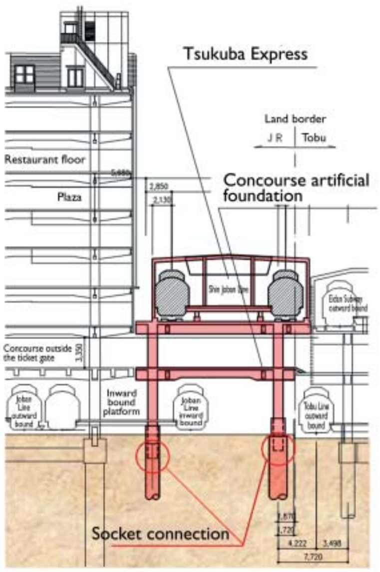

Fig.5: Cross Section of Kitasenju Station

3.3 Lower End Pre-loaded Piles Constructed On-site

When installing piles that support a structure in restricted space, measures need to be taken with respect to noise and vibration, and the normal method of doing this is excavation using machinery, constructing a steel reinforced concrete casing, and driving the piles on site. However, due to the looseness of the foundation at the lower end of the pile or the sedimentation of soft material that is normally called slime, there is a divergence in the actual support strength of the pile, and subsidence as shown in Figure 6 (a) may occur. Moreover, in order to prevent this, the diameter of the pile needs to be increased or the length elongated.(b) Lower End Pre-

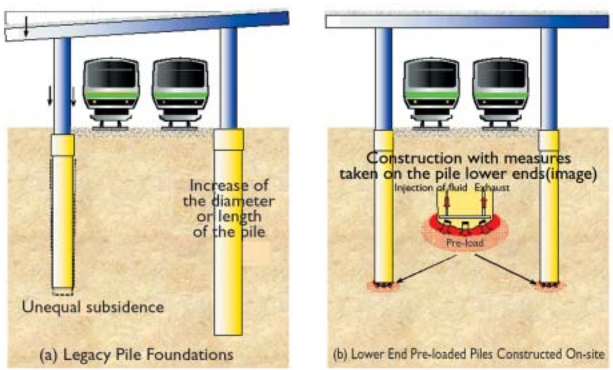

Fig.6: Piles with Strengthened Tips

For this reason, after hardening of the pile concrete, cement milk was extracted from the back which had been attached to the tip of the steel to eradicate slime and to strengthen the foundation at the lower end of the pile. Thus, a lower end pre-loaded on-site pile construction method Figure 6 (b) was developed (Note 3). A back that unfailingly spreads in the soil was found and a method of confirming the enhancement of support was developed. As a result, compared to piles for which no measures were taken, support increased by 30%. Today, this method is being used in the artificial foundation at Nishi Funabashi Station and the elevated tracks from Mitaka to Tachikawa on the Chuo Line.

3.4 Strand On-site Construction Pile

In the case of construction where there are impediments overhead, using the reinforced concrete on-site installation requires insertion through extending the reinforced concrete cage as shown in Figure 7 (a), thus increasing the cost.

For this reason, by using an easily bendable strand as the main steel material in place of the normal material used, the strand on-site construction pile method, which does away with the joining method, as shown in Figure 7 (b) was developed. The making of the strand is shown in Figure 8. The strand that is used is not only more flexible than iron bars but has weak adhesiveness to concrete, is extremely strong, and has low elongation properties. An experimental model was created and destruction property testing conducted with the strand used as the major steel material (Note 4). As a result, other than taking into consideration the reduction in the hardness of the material, it was recognized that construction may be carried out in the same way as normal steel reinforced piles. The strand on-site pile

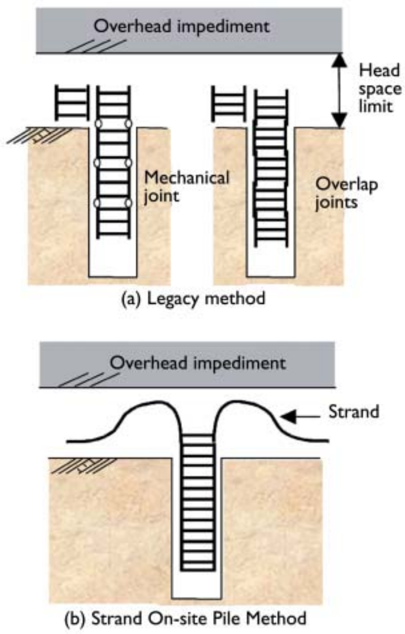

Fig.7: On-site Pile Method for Overhead Impediments

Fig.8: Construction of the Strands

method was jointly developed with Taisei Corporation.

This strand on-site pile construction method was used at Akihabara Station where the minimum head space was 2.7 meters and was able to reduce the construction cost by about 10%. Moreover, the bending property of the strand may be utilized to develop technology for undertaking pile construction during both the day and night.

4 Technical Development Towards Reducing Cost of Underground Construction

Older railway lines involve railway tracks and stations that are built on solid earth or earth-fill. If it is possible to maintain the functions of the tracks and stations and to remove the soil from under these facilities to produce space, a precious space resource may be obtained as in the case of artificial foundations constructed in the space above the tracks. Since construction of space under tracks will involve temporary supports and removal of soil, the cost is higher than for the construction of an artificial foundation. Various development initiatives are being taken in order to overcome this problem.

4.1 Reduction of the Cost of Temporary Construction Girders

When constructing underground space, temporary construction girders are normally installed crosswise to the tracks and the soil beneath these girders is excavated. These girders may be temporary, but in any event, must support trains for several months to several years. In order to ensure safety, specifications must be followed and if the reduction of the volume of steel material to be used is attempted by using ground beams, the processing of the steel material and in particular of the welding work increases as shown in Figure 9 (a), leading to greater cost.

For this reason, as shown in Figure 9 (b), a method of joining whereby the steel plates are not welded and using section steel for the main girder, shelf board, and ground beam using high tensile bolts was developed (Note 5).

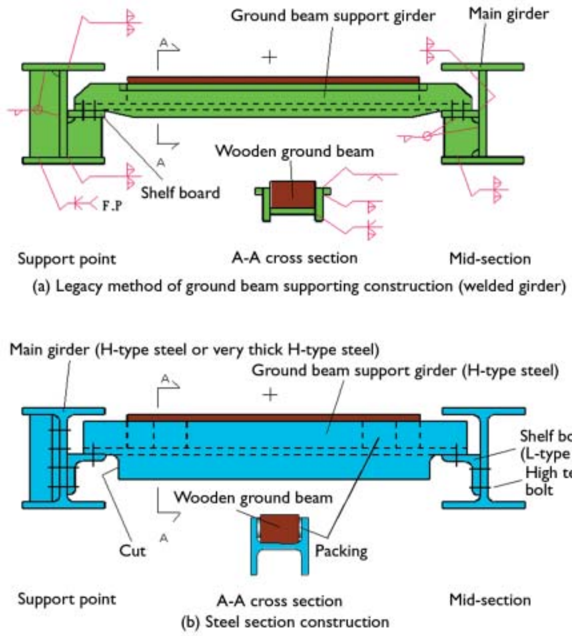

Fig.9: Reduction of the Cost of Temporary Construction Girders

FEM analysis and a model experiment were conducted on the detailed status of diversion and the measurements of stress on an actually installed steel section was performed to ensure safety.

This steel section constructed girder requires about 10% more material compared to normal methods of construction but the reduction of the processing of steel and welding results in an overall cost decrease of about 25%.

This method has been used for 25 steel section girders in the construction at six locations since 2001, including the underground sewer system at Narita Station and the underground free passageway at Morioka Station.

Additionally, development is underway for use with PC ground beams and methods of using the construction girders in place as structural components after completing the construction as a way of further increasing strength.

4.2 Traverse Construction Under Tracks without Excavation

The method of forming a tunnel under tracks without using temporary construction girders is called non-excavation construction and if this can be undertaken safely and the cost reduced, this will form a potent method for constructing underground space.

(1) HEP Method (High Speed Element Pull Method)

Non-excavation construction methods of the past involved injecting

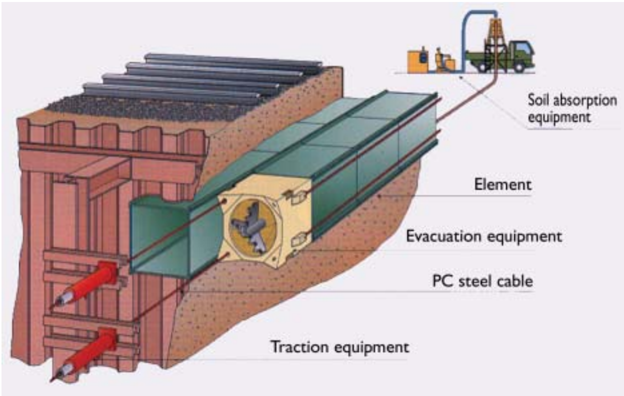

Fig.10: HEP Method

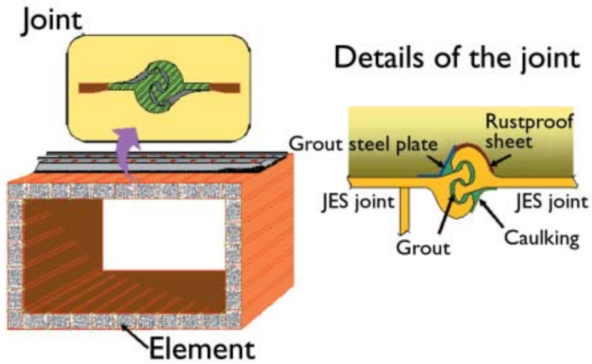

Fig.11: JES Method

an element (material to be injected into the soil) using a propeller from the starting side. For this reason, there were problems involved in the extent of the injection being inaccurate or the time required for the construction being excessive.

Because of this, the HEP method has been developed whereby the PC steel that is fixed to the excavation position is pulled using traction equipment to pull the element that is directly connected to the excavation equipment from the starting side (Figure 10). This method is being improved through further consideration of the traction equipment and tests on removal of soil (Note 6).

Since the element is installed at a specified position on the starting side and traction force applied from a specified position on the destination side, the reactive equipment may be downsized, thus improving the installation precision on both the starting and destination sides. Moreover, since the joint between elements may be simple joints that are sufficient to convey the force of traction, the time required for the joining to be accomplished has been reduced, thus speeding up the construction.

(2) JES Method (Jointed Element Structure Method)

In legacy non-excavation methods, the element that was injected into the soil had the function of (1) being able to temporarily support the track like a pipe loop; and (2) being used as a guide for pouring large amounts of reinforced concrete at later stages. For this reason, (1) soil removal (the perpendicular distance from the track surface to the structure) was great and (2) it was necessary to undertake propulsion under the tracks twice, something that ought to be avoided for safety reasons.

In order to avoid the above, the JES Method adopts a joint that is capable of conveying the force that acts in the axial direction on the element that is buried in the ground, and it allows constructing bent method or circular structures without limitation (Figure 11). The method is adequately resistant to fatigue and joints that are easy to use have been developed (Note 7).

Safety has improved due to the facts that the soil is excavated after completion of the structure in a system, the element needs to be inserted below the track only once, and the elements require small cross sections of about only one meter in the horizontal and vertical directions. Moreover, since the steel elements that had been used in the past for protective purposes may now be used as part of the main structure, the construction time has been reduced. This has resulted in a reduction of between 10% and 20% of the cost compared to legacy methods of construction.

There are many examples in which the HEP Method and JES Method are concurrently used such as in the Rinkai Line Second Hiromachi Tunnel or in construction work involving installing roads or waterways below tracks. Figure 12 is underground space constructed using both HEP and JES methods. The HEP and JES methods were jointly developed with Tekken Corporation.


Fig.12: Underground Space Constructed using the HEP & JES Methods

5 Conclusions

Methods of design and construction have been developed and are being used in individual construction work towards reducing the cost of construction for creating new space. Moreover, in order to reduce the cost and to close the gap with the objective, the company will proactively employ cutting edge construction and civil engineering technology and technologies from other fields. The future issue is how methods of design and construction may be matched to the railway system in order to ensure that trains and tracks are not impeded.

JR East Railway Company is promoting the creation of new stations in its "Station Renaissance Program" under the concept "A Station to be Visited Rather than Transited." A station is not merely a facility for boarding or disembarking from trains, and active innovation in station space is being planned. Barrier-free environment and alleviation of congestion will be promoted and in order to realize a station that offers comfort and latitude, new stores need to be created in the stations for passenger convenience and invigoration of the community around the station. To this end, the space above tracks must be used as artificial foundation and the space under tracks as underground space, limiting the cost of construction to the extent possible. The company will work towards technical development that will allow achieving such reduction in costs.

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