

OVERVIEW OF THE DEVELOPMENT PROCESS AND EFFECTS OF THE UFO METHOD (ACCELERATED CONSTRUCTION METHOD FOR OVERPASSES)

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Abstract

Traffic congestion at intersections is a serious problem in urban Japan because it causes economic loss and environmental degradation. Shorter construction periods and minimal traffic restrictions are needed to prevent further congestion during the construction of overpasses. The Uni-Fly-Over (UFO) method was developed to achieve dramatically shorter construction periods through structural rationalization for foundations. This paper describes projects for which the UFO method has been used to reduce construction time, explains the method's advantages such as its mitigation of environmental degradation, and outlines a review on the technical issues that had to be overcome to develop steel spread foundations.

Introduction

According to a recent survey conducted by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), there are over 2,000 intersections throughout Japan that are in need of a solution to the problem of traffic congestion. This indicates that the mitigation of traffic congestion at intersections and railroad crossings is a key issue in realizing an improvement in urban road functions.

Although overpass of intersections is an extremely effective technique for alleviating traffic congestion, the construction of a grade-separated junction in areas suffering from congestion creates further congestion due to the traffic restrictions that must be enforced during the work or aggravates the roadside environment as a result of the noise and vibrations generated in the course of the work.

Given this, there is a growing social need for an accelerated construction technology that will reduce the economic loss that results from traffic restrictions and avoid environmental deterioration by shortening the construction period for overpasses.

The UFO method was developed in 1989 by Hitachi Zosen Corporation to provide an engineering solution to society's demands for a technology that would accelerate the construction of an overpass with a spread foundation. This method has been applied in the construction of three bridges to date. The greatest advantage of this method is the considerable reduction in local construction time it offers by enabling the use of lightweight, prefabricated steel members in the construction of the foundations, which has been a very time-consuming task until now.

This paper describes the development concept and characteristics of the UFO

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method and explains its advantages by looking at actual cases in which the method has been applied. The paper also outlines a review made of the technical problems involved in the development of the steel spread foundation, one of the characteristic features of the UFO method, based on some case studies.

Development Concept

The principal purpose of developing the UFO method was to reduce the local construction time for overpasses—including the construction of the superstructure, substructure, and foundations—and to minimize the period of time for which traffic restrictions are imposed. Its development involved the study of conventional problems and their potential solutions. Once that had been done, a method that satisfied the following conditions was realized:

- 1) Earthwork and concreting work, which are both time-consuming activities performed at the work site, should be minimized.
- 2) Members should be prefabricated and a structure that reduces the construction time at the work site should be used.
- 3) Structural rationalization and downsizing should be carried out with respect to the foundation structure, whose construction takes place mainly at the work site and is very time-consuming.
- 4) The retaining wall at the approach should be constructed at the same time as the overpass.
- 5) The members should be erected using readily available machines, and members that can be erected without the use of special equipment should be used to ensure the universality of the method.

Originally intended for use in the construction of spread foundations that are laid on the bearing layer about 5 m underground, the UFO method was developed to satisfy the above-mentioned five conditions. The aim was to achieve a substantial reduction in the local construction time of over 50% compared with conventional methods. An accelerated construction method for pile foundations that was intended for deeper bearing layer was developed jointly by PWRI and Hitachi Zosen. Known as the Uni-Anchor System, it provides a rational combination of steel pier and pile foundations, as shown in Fig. 1. (PWRI, 2005; Mishima et al., 2005)

Characteristics of UFO Method

Fig. 2 provides a structural overview of the UFO method that was developed based on the above-mentioned concept. The structural features are as follows:

1) Continuous steel rigid-frame box-girder bridge with steel deck and integrated superstructure and substructure

To facilitate quicker construction work, the superstructure and substructure are constructed using prefabricated steel piers and box girders with steel deck. An integrated rigid-frame structure is employed for the superstructure and substructure to

provide enhanced earthquake resistance. As this structure also eliminates the need for bearings and expansion joints, it also provides a smoother ride for vehicles and saving in maintenance costs.

2) Steel spread foundations

As the superstructure and substructure of a conventional overpass are made of a concrete structure with a substantial dead load, larger foundations are inevitably required. This not only necessitates an extension of the work period, but also an enlargement of the work yard, which ultimately means that strict traffic restrictions have to be imposed for the roads at and around the construction site.

The UFO method offers a reduction in weight because the use of steel members for the superstructure and substructure results in the foundations being subjected to a smaller load, enabling prefabricated steel members to be used for the foundation structure. More specifically, a foundation structure built using the UFO method consists of steel members—namely, supporting beams and connecting beam—laid out in a grid pattern with a thin reinforced concrete slab laid underneath them, as shown in Fig. 2. The load from the superstructure and substructure is efficiently dispersed into the ground from the steel members arranged in a grid pattern via the footing. Fig. 3 compares the reaction dispersion mechanism for the UFO method with that of a conventional method. As shown in this figure, the spread foundation is divided into two types: continuous footing along the bridge axis (hereinafter, “continuous footing”), which is a series of steel footings installed between piers along the bridge axis; and isolated footing along the bridge axis (hereinafter, “isolated footing”), which is a single steel footing installed for each bridge pier along the bridge axis. Continuous footing is generally employed when the bearing capacity of ground is relatively low and a large foundation would be required if isolated footing were used. It is also used if it is necessary to disperse the subgrade reaction into the ground as a result of the interaction between the foundations and any underground buried objects. On the other hand, isolated footing is generally employed if any underground buried objects present has no impact on the foundations and the bearing capacity of ground is relatively high.

As mentioned earlier, the UFO method makes use of prefabricated members for almost all the members of both the superstructure and substructure and compact members for the foundation structure. It therefore realizes a significant reduction in the work period and the size of the work yard compared with conventional methods.

3) On-site construction method

The basic method for erecting steel members involves the use of truck cranes, which are economic, versatile, and highly mobile. Use of this erection method enables the following to be achieved: a reduction in the size of the work yard, the cyclic erection of members using the dividing strip as the work yard, and the simultaneous construction of approach section (retaining wall).

The Harada Viaduct is shown in Fig. 4 as an example of the standard procedure employed with the UFO method. As the figure shows, the procedure involves ground excavation for installation of a pier foundation and construction of the concrete slab. This is followed by the cyclic erection of the foundation members, bridge piers, and

the superstructure, in this order. After the erection of the side spans has been completed, the central spans are erected in the direction of the intersection, and finally upper spans are set in place directly above the intersection. Since the degree of precision achieved in the fabrication of the steel members has a great impact on the degree of precision achieved in their erection, the finished quality of the members needs to be strictly controlled by temporary assembly in a fabrication shop, as shown in Fig. 5.

UFO Method Case Studies

1) Kitahanada Overpass

Conditions at the construction site for the Kitahanada Intersection (located in Sakai city, Osaka prefecture) were extremely challenging because the area in which it is located is home to a major intersection and the Kitahanada subway station. To achieve an uninterrupted traffic flow at this junction, Osaka Prefecture began a project to construct what would become known as the Kitahanada Overpass in 1994, and construction work was completed in 1996. The UFO method was employed for this project so as to realize a considerable reduction in construction time and minimize the impact of the overpass on the subway station structure.

The overpass is a 15-span continuous steel rigid-frame box-girder bridge with steel deck, as shown in Fig. 6. When the structural composition of the overpass was first planned, a design had to be devised that would ensure that the bridge construction would have no impact on the subway station structure. This was necessary because when the subway station was constructed, no consideration had been given to the possible addition of any extra load. Specifically, the steel spread foundation was buried underground and lightweight EPS (expanded polystyrene) was used as backfill to make the weight of the excavated soil equal to the weight of the bridge structure. To ensure an even dispersion of the subgrade reaction, a continuous footing was also employed for the steel spread foundation, based on which the bridge pier intervals were determined. In addition, the soil under the bridge piers was improved to achieve uniform bearing capacity of ground.

Since this was the first time that a foundation structure had ever been built using the UFO method, a 1:10 scale model, as shown in Fig. 7, was produced to conduct loading tests. These tests confirmed its safety with respect to the subway station building.

Thanks to the UFO method, the superstructure and substructure were completed in just 12 months. It was estimated that had a conventional method been taken, it would have taken 27 months to build a rigid-frame bridge comprising 2-span continuous non-composite steel I-girder and 3-span continuous steel box girder with steel deck as the superstructure and a pile foundation as the substructure. This means that a reduction ratio of over 50% was achieved. (Hayakawa et al., 1997)

2) Harada Viaduct

The Shikoku Regional Development Bureau of the MLIT decided to employ an accelerated construction method in the construction of a viaduct over the Harada

intersection (Marugame City, Kagawa Prefecture) to mitigate traffic congestion and prevent traffic accidents. In selecting the construction method during the development of the basic plan, the Shikoku Regional Development Bureau chose to review 12 accelerated construction methods that might be suitable, comparing them on the basis of construction period, cost, and constructability. Following this review, the UFO method was adopted as the standard method because it had a proven track record and received high evaluations overall. Tenders were invited in 2003 for the construction of a viaduct over the Harada intersection, and the tenderers were screened using the comprehensive evaluation method for which the main evaluation items were the construction fee and how few days the project could be completed in. The project was successfully completed in 2004. Fig. 8 shows the erection work and the completed viaduct.

The viaduct is a 7-span continuous steel rigid-frame box-girder bridge with steel deck, as shown in Fig. 9. Because a bearing layer with an N value of 30 or more was found at a depth of 3 to 8 m from the ground surface of the site, it was possible to use fewer bridge piers in the plan for the viaduct's structural composition than were required for the Kitahanada Overpass, which had extremely challenging ground conditions. Soil improvement was also conducted to reduce the amount of earth that would need to be excavated, which eventually helped to minimize the number of on-site construction days required. Continuous footing was used since a uniform distribution of reaction in the improved soil was needed for the steel spread foundation.

With construction of the superstructure and substructure completed in just 250 days, the UFO method achieved a 60% reduction in the on-site construction period, as shown in Table 1. In contrast, it was estimated that had a conventional construction method been used, it would have taken 630 days to construct a hollow PC slab bridge and a simple composite steel I-girder bridge as the superstructure and an RC bridge pier and RC spread foundation as the substructure and foundation. This reduction in the construction period meant that the method was also able to reduce the traffic restriction period by 40%.

To assess the economic efficiency of the method, the time lost as a result of congestion during the traffic restriction period and the time gained as a result of the early opening of the roads were calculated in monetary terms, the results of which were then evaluated together with the construction cost (see Fig. 10). This revealed that using the UFO method is about 20% more expensive than the conventional method, but about 2% more advantageous in terms of a comprehensive evaluation of losses arising from congestion and gains from the early opening. Further advantages are known to be gained from the use of the UFO method, including the prevention of the environmental degradation, which cannot be valued in monetary terms and a reduction in losses from disruption to goods distribution. (Yamada et al., 2005)

3) Tonyamachi Overpass

In 2007, the Kanto Regional Development Bureau of the MLIT invited tenders for a project to construct a viaduct over the Tonya intersection (located in Utsunomiya City, Tochigi Prefecture) to mitigate traffic congestion at the intersection point.

Executed as a package contract for the design and construction of the overpass, the project involved large-scale construction work over a length of road totaling 1,190 m in length that included the construction of an elevated bridge and approach as well as road improvements to the section under the intersection. A joint venture in which we, Hitachi Zosen Corporation, participated won the contract because our proposal offered an on-site construction period that would, thanks to the use of the UFO method for the construction of the overpass, be 50% shorter than the employer's requirement and because our bid price was the lowest of the three joint ventures who participated in the tender. The project is currently underway, with completion scheduled for March 2010.

The overpass is a 3-span continuous steel rigid-frame box-girder bridge with steel deck as shown in Fig. 11. The dimensions of the bridge and the retaining wall were determined in such a way as to achieve a good balance between the construction cost and a reduction in the construction period. In addition, isolated footing, rather than continuous footing, was used for the steel spread foundation because, unlike for the Kitahanada Overpass or the Harada Viaduct, underground buried objects had no impact on the work, the bridge length was short, and the supporting ground had sufficient strength. This rationalization allowed us to plan for a reduction in the standard on-site construction period set by the employer of over 50%.

Technical Review of Steel Spread Foundations

1) Outline

The greatest advantage of the UFO method is its ability to significantly reduce the on-site construction period and the size of the work yard by employing a steel spread foundation composed of prefabricated members that are both lightweight and compact. The use of such a steel spread foundation was unprecedented, and the greatest challenge posed by the application of this method was to ensure its safety.

There are two types of steel spread foundation used in the UFO method: continuous footing and isolated footing. Which of these methods is employed depends on the bearing capacity of ground and the conditions of any underground buried objects, as earlier mentioned.

Reviews conducted of these two types of footing are outlined in the following sections using the Harada Viaduct and Tonyamachi Overpass Bridge as case studies, with a particular focus placed on safety.

2) Continuous footing

If a spread foundation is being considered for use as a rigid foundation, as is conventionally done for a reinforced concrete footing, its safety should be verified against the Specifications for Highway Bridges (Japan Road Association, 2002), and the footing should then be designed to be thick enough to be verified as a rigid entity in accordance with the said specifications. If a footing is confirmed to be thick enough as a rigid body, this means that the equations for calculating the bearing capacity of ground or subgrade reaction as specified by the Specifications for Highway Bridges are determined based on the assumption that the footing in question is a rigid body. The type of spread foundation used for the Kitahanada Overpass and the Harada Viaduct

was a continuous footing both along the bridge axis and in the direction perpendicular to the bridge axis. For the direction perpendicular to the bridge axis, the rigidity of the foundation as a rigid body can be maintained because of a shorter footing span. For the direction along the bridge axis, however, since the footing span is 14 to 21 m, it is not rational either in terms of structure or construction for the footing to have sufficient thickness as a rigid body. Therefore, it was necessary to consider the continuous footing as an elastic foundation and to check the stability in terms of bearing capacity, toppling, and sliding by taking into account the uneven distribution of the reaction from the superstructure and substructure. Typical safety check methods include loading tests using a scale model, as in the case of the Kitahanada Overpass, and finite element analysis. The finite element analysis used for the Harada Viaduct is explained below to serve as an example.

For the Harada Viaduct project, both the local ground and the steel foundation members determined relative to external forces during the design stage were modeled for review using three-dimensional finite element analysis, which can accurately consider the impact of the three-dimensional ground supporting the spread foundation, as shown in Fig. 12. For a conventional type of spread foundation, only a test load equivalent to the load that would occur in the event of a Level 1 earthquake is used due to the behavioral characteristics of the foundations in the event of a major earthquake. But since no behavioral characteristics for a steel spread foundation have been identified yet, the load that would occur in the event of a Level 2 earthquake was used for the safety check to err on the side of caution.

The distribution of the level of vertical stress on the ground is shown in Fig. 13 as an example of the analytical results. This figure indicates that no stress in excess of the allowable value was exerted on the ground and that stress was generally dispersed across all of the ground at a depth of 6 to 7 m. The results for toppling and sliding also revealed no problems.

In conclusion, the safety of steel spread foundations was verified using three-dimensional finite element analysis, which takes into account the three-dimensionality of the ground.

3) Isolated footing

If the ground strength is relatively high and underground buried objects do not cause any major problems, isolated footing that is compact and easy to construct serves best, as was the case with the Tonyamachi Overpass (Fig. 11). However, for an isolated footing, steel spread foundation members are cantilevered along the bridge axis, which eventually causes a concentration of the reaction just under the bridge pier if the footing rigidity is low. Therefore, it is necessary to provide steel members with a level of rigidity that is as high as that of a conventional spread foundation so that the reaction force of the superstructure and substructure acts uniformly on the ground.

As has already been mentioned, the required rigidity for a spread foundation is specified in the Specifications for Highway Bridges. However, the provisions in these specifications are meant for conventional spread foundations, which are made of

reinforced concrete of high rigidity. As such these specifications cannot be applied directly for lightweight, relatively flexible foundations such as foundations made of steel members and thin concrete slabs, as used in the UFO method. For a steel spread foundation, therefore, it was necessary to verify whether the steel foundation members, whose cross section had been determined in the design stage according to the external forces to which they would be subjected, possessed the required rigidity.

As a result, three-dimensional finite element analysis was used to verify this, as was the case with the Harada Viaduct. Given that the subject for analysis was an isolated footing, a partial model was used, as shown in Fig. 14. To be on the safe side, the loads to be checked included those that would occur in the event of Level 2 earthquake. The section forces of the pier base, which were calculated from a separately conducted dynamic analysis, were applied to the end of the model as a boundary section force.

The rigidity of the steel spread foundation was evaluated based on an existing research paper (Iijima, 1981) that served as the basis for the rigidity judgment adopted in the Specifications for Highway Bridges. More specifically, attention was paid to the level of subgrade reaction intensity, and the difference between the subgrade reaction intensity (P_{mean}) for a spread foundation as a rigid body and the maximum subgrade reaction intensity (P_{max}) for a steel spread foundation was expressed as a ratio to P_{mean} (see Fig. 15). This ratio is taken as the dispersivity of reaction. If the allowable level of this dispersivity is within $\pm 20\%$, the foundation should be taken as a rigid body.

As an example of this result, the distribution of the subgrade reaction in the event of a Level 2 earthquake in the direction perpendicular to the bridge axis is shown in Fig. 16. As the figure shows, the dispersivity of the subgrade reaction is within the allowable limits. This confirms that steel spread foundations have sufficient rigidity.

Highly precise results may be obtained from a rigidity evaluation of a steel spread foundation if finite element analysis is used, but considering the time and money it would take to carry out such an analysis every time one was necessary, a simplified evaluation equation would be of great benefit for the actual design work.

Conclusion

This paper presents an outline of how the UFO method, an accelerated construction method used to mitigate congestion at intersection points, was developed and introduces some projects for which the method was applied. The projects for which the UFO method was applied turned out to be successful in terms of the intended goal of achieving a significant reduction in the construction period, despite differences in their on-site conditions.

The following points summarize the conclusions of this paper.

- 1) The UFO method can be successfully used to reduce the on-site construction period by over 50% compared with conventional methods, although the actual reduction varies according to the local conditions.
- 2) A reduction in the on-site construction period will produce various other advantages, including a reduction in the traffic restriction period and

- mitigation of the negative impact on the environment.
- 3) The UFO method uses two types of spread foundation: continuous footing, which is a series of steel footings along the bridge axis, and isolated footing, which is a single steel footing along the bridge axis. A significant reduction in the on-site construction period can be achieved by selecting the type of foundation suited to the bearing capacity of ground and the conditions of any underground buried objects.
 - 4) Loading tests with a scale model or 3D FE analysis with a local ground model have verified that steel spread foundations are safe in the event of a Level 2 earthquake.

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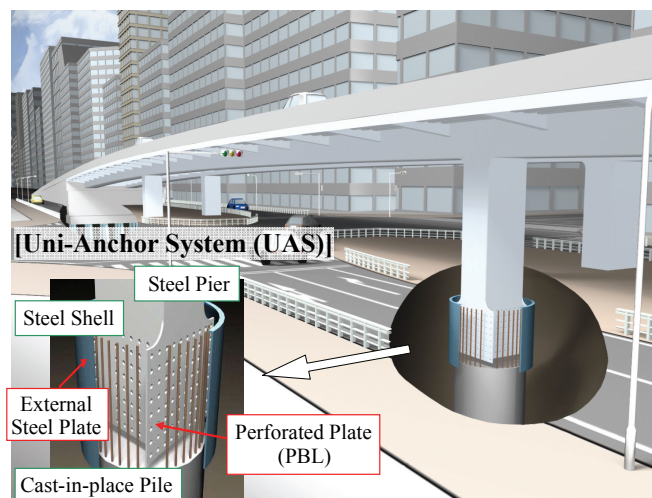


Fig. 1 Structural Overview of the Uni-Anchor System

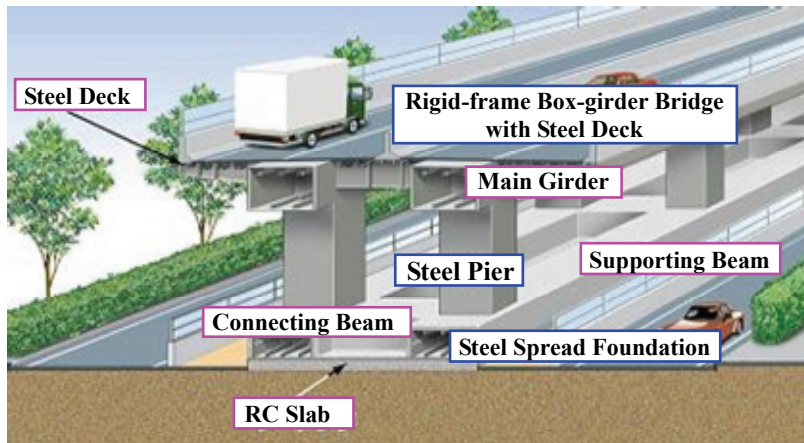


Fig. 2 Structural Overview of the UFO Method

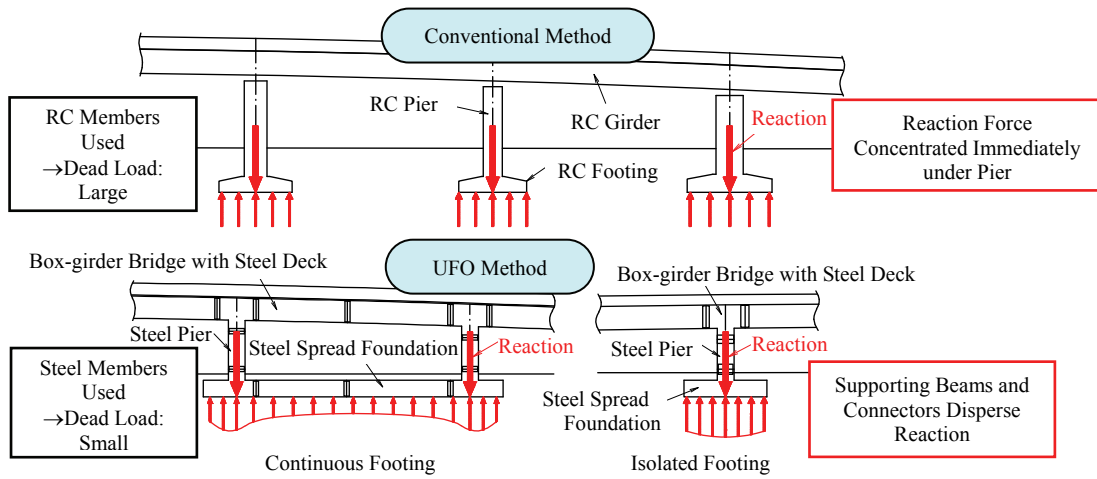


Fig. 3 Comparison of Reaction Dispersion Mechanisms

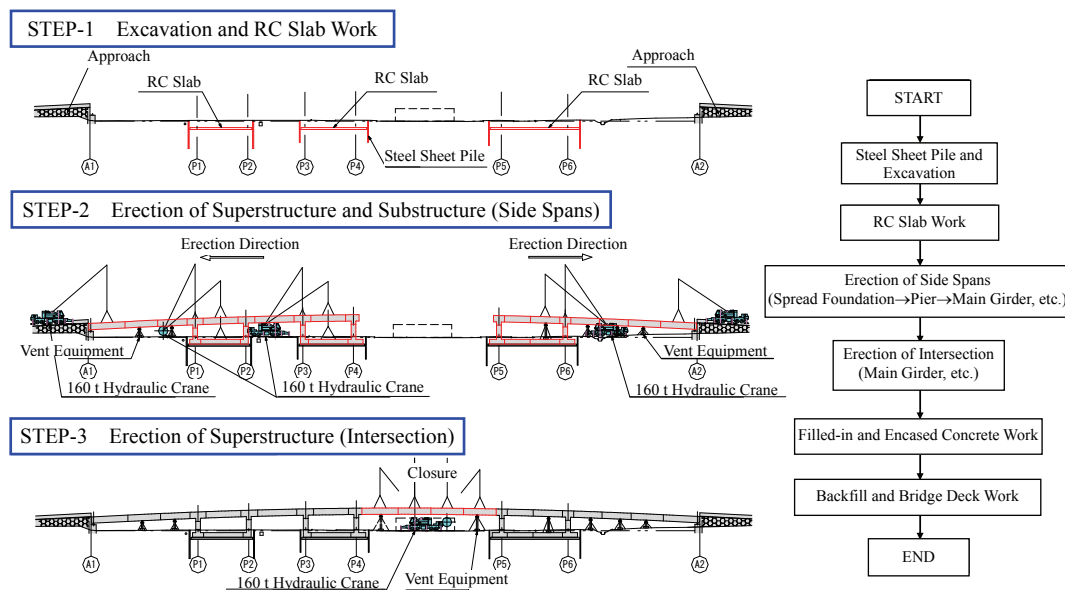


Fig. 4 Standard Construction Procedure (Harada Viaduct)



Fig. 5 Temporary Assembly for a Steel Spread Foundation (Harada Viaduct)

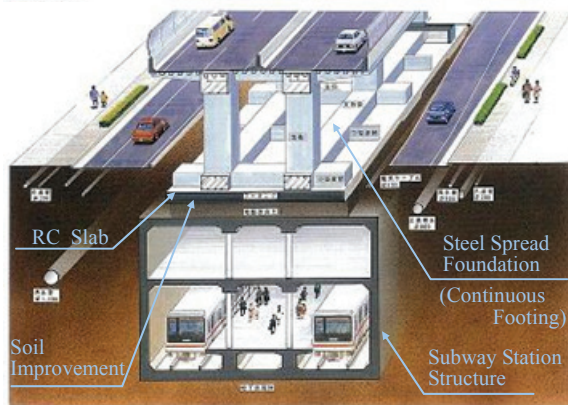
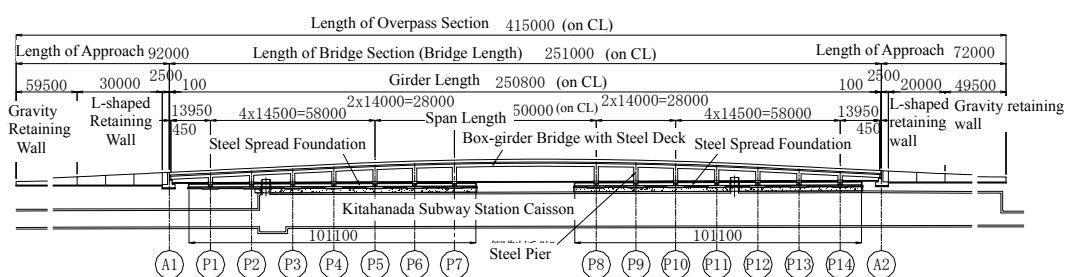


Fig. 6 Structural Overview of the Kitahanada Overpass



Fig. 7 Loading Test with a Scale Model



Steel Spread Foundation
(Continuous Footing)



Full View of the Completed Viaduct

Fig. 8 Erection Work and Full View of the Harada Viaduct

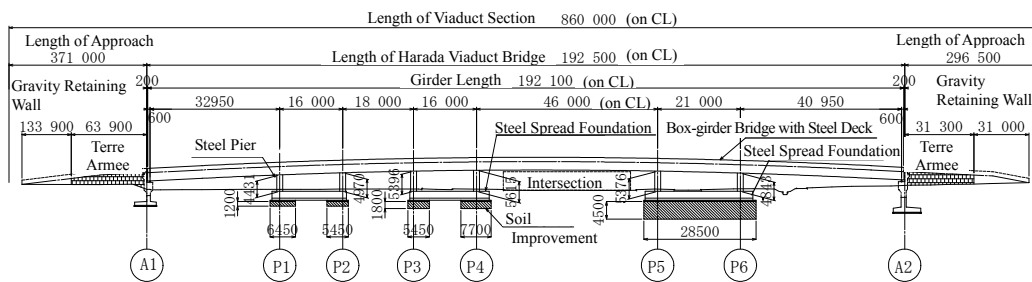


Fig. 9 Construction Plan for the Harada Viaduct

Table 1 Comparison of Construction and Traffic Restrictions Period

Month		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Work Period for Entire Project	Conventional method	750 Days (25 Months)																									
	UFO Method	450 Days (15 Months)															Saving of 300 Days (40% Reduction)										
Work Period for Overpass	Conventional method	630 Days (21 Months)																									
	UFO Method	250 Days (8.3 Months)								Saving of 380 Days (60% Reduction)																	
Overpass Work Traffic Restrictions	Conventional method	315 Days (10.5 Months)																									
	UFO Method	185 Days (6.2 Months)						Saving of 130 Days (40% Reduction)																			

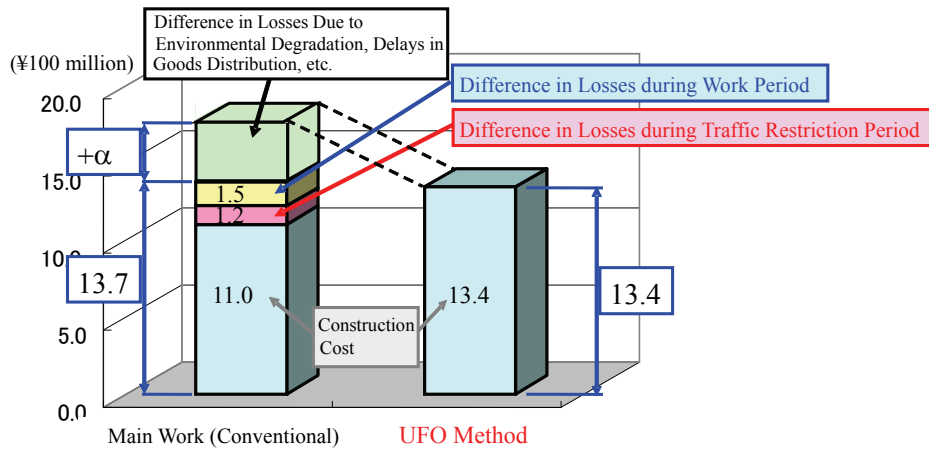


Fig. 10 Economic Benefits of the UFO Method (Evaluated by MLIT)

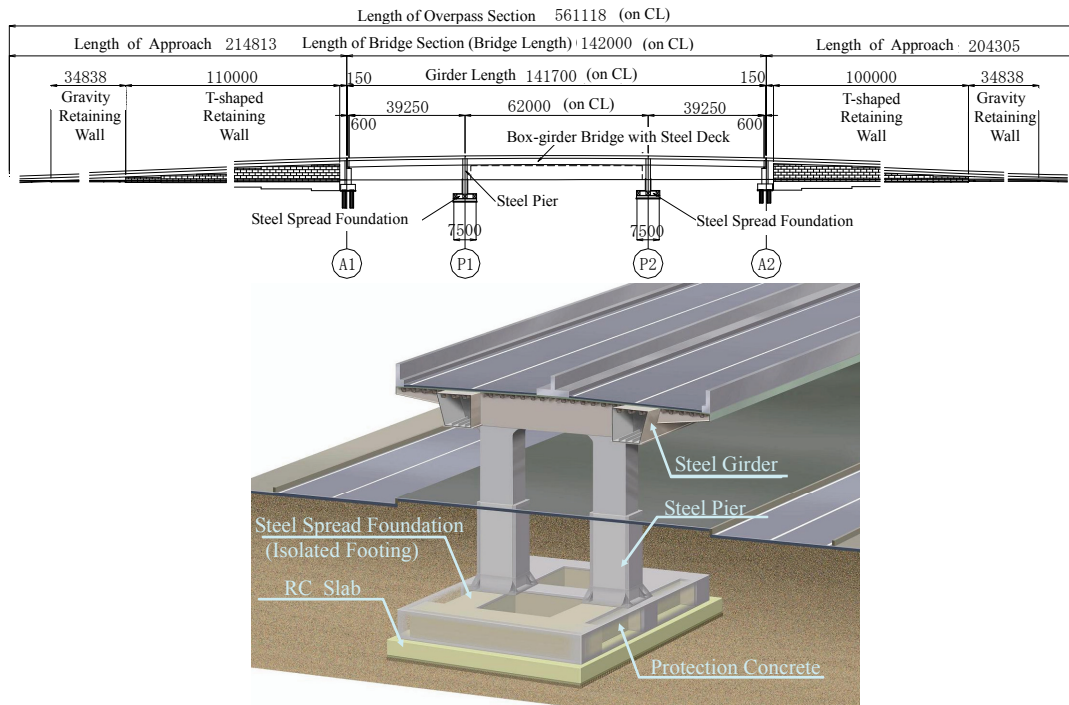


Fig. 11 Structural Overview of the Tonyamachi Overpass

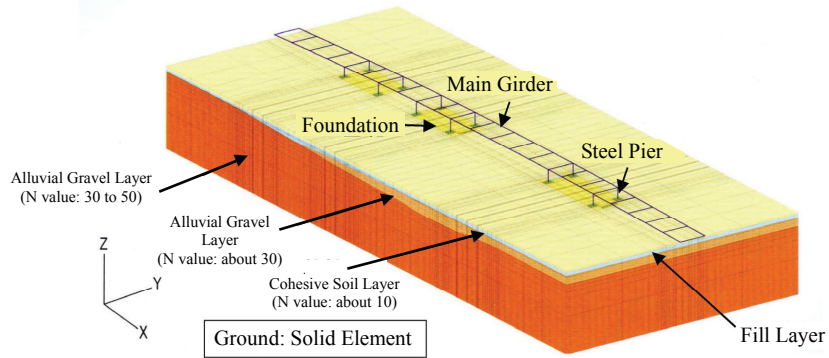


Fig. 12 Three-dimensional FE Model (Harada Viaduct)

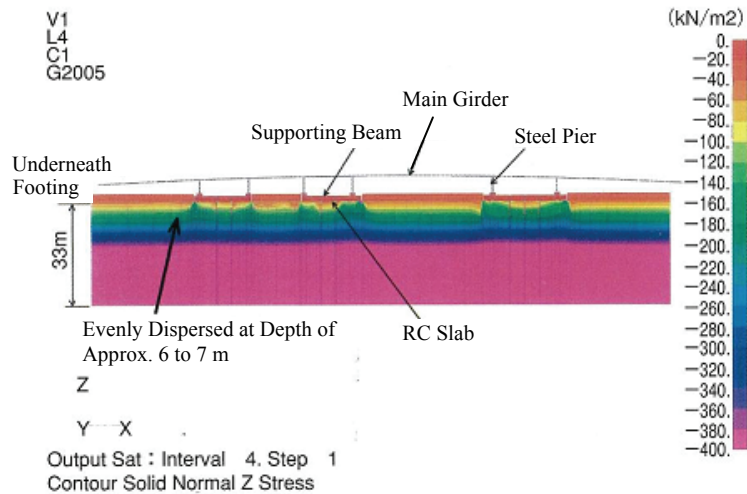


Fig. 13 Example of Analysis Result (Subgrade Reaction Distribution)

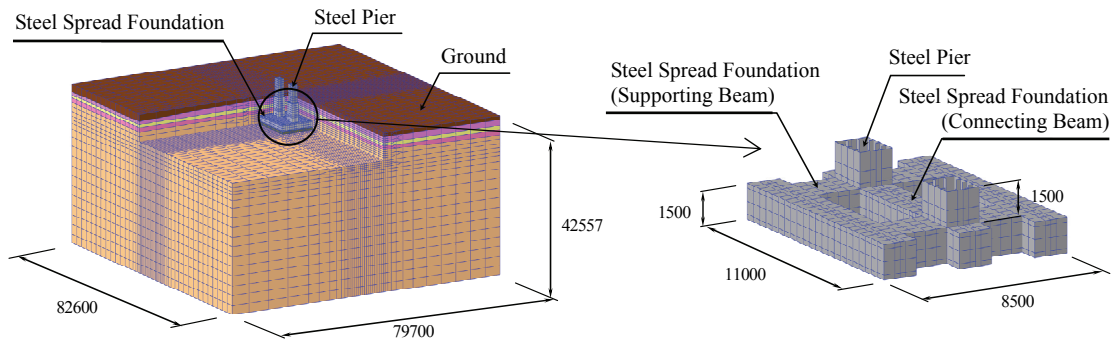
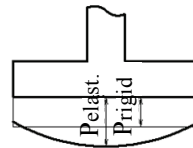


Fig. 14 Three-dimensional FE Model (Tonyamachi Overpass)

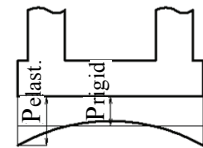
Dispersivity of Subgrade Reaction
$$\bar{P} = \frac{P_{\text{elast.}} - P_{\text{rigid}}}{P_{\text{rigid}}} \leq \pm 20\%$$

$P_{\text{elast.}}$: Subgrade Reaction Intensity of Steel Spread Foundation as an Elastic Body

P_{rigid} : Subgrade Reaction Intensity of the Footing as a Rigid Body

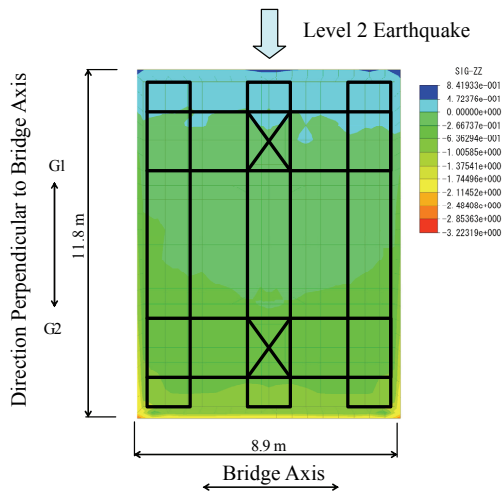


Bridge axis direction

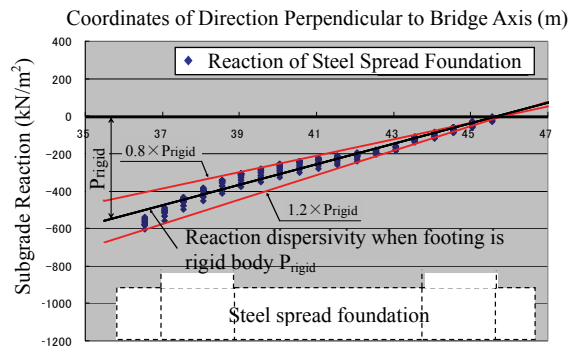


Direction perpendicular to bridge axis

Fig. 15 Judgment of Rigidity Body



(a) Subgrade Reaction Contour



(b) Subgrade Reaction Distribution

Fig. 16 Example Judgment Result for Footing Rigidity