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Quick Closing Integral Bridge Method "QCIB"†

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Abstract:

The JFE Group (JFE Engineering, JFE Steel, and JFE R&D) has developed a QCIB (quick closing integral bridge) Method, which enables quick, safe, economical construction of grade separation bridges at intersections in urban areas by designing the entire bridge, including the foundation, as a bridge system. The QCIB Method consists of several established core technologies on fundamental design and construction. This paper presents an outline of the QCIB Method and core technologies.

1. Introduction

With conventional techniques, construction of grade separation bridges at intersections in urban areas causes additional traffic congestion due to traffic restrictions accompanying the construction work, and the work must be executed in locations with severe limiting conditions. As a result, the construction period has tended to be long, and the work has had a serious impact on roadway traffic. Moreover, the vibration and noise caused by construction over extended periods affect the living environment of neighboring residents. On the other hand, road intersections and railway crossing frequently cause bottlenecks in urban traffic, which also requires a solution. To solve these problems, the JFE Group developed the QCIB (quick closing integral bridge) Method, which significantly shortens the work period when constructing grade separation bridges at intersections and railway crossings and can be executed in a restricted space with little impact on roadway traffic or the neighboring environment.[1,2)]

The QCIB Method centers on core technologies which include established fundamental design methods and construction methods, and aims at rationalizing the structure of the bridge system as a whole, including the foundation, substructure, and superstructure, with constant attention to weight reduction and prefabrication. The method was developed by reconstructing these techniques in combination with a quick-closing method. This paper describes the newly developed quick-closing integral bridge method.

2. Technical Tasks in Development of Quick-closing Method for Intersection Grade Separation Bridges

The goals of development of this construction method were to achieve a substantial reduction in the site work period, alleviate secondary congestion caused by the work, and control costs to the same as or less than those with conventional techniques. The technical tasks in development included the following:

(1) Maximum prefabrication of members, considering the limited work yards available on existing roadways.
(2) Development of optimum structure and construction method, assuming a system where the bridge piers and superstructure, which are assembled separately during foundation work, are delivered and connected to the foundation as a unit.
(3) Establishment of design and construction planning techniques which make it possible to perform work on the superstructure and substructure in parallel. Particular importance was attached to the development of compact construction machinery for foundation work and bridge erection on the soft ground typical to urban areas.

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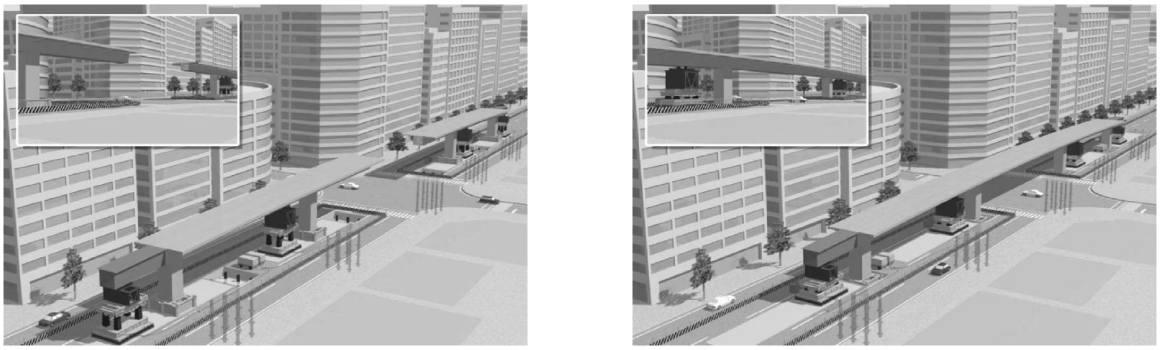


(a) Before closing (b) After closing

Fig. 1 Conceptual configuration of QCIB Method

3. Features of Construction Method

The features of the construction method, as illustrated in **Fig. 1**, are summarized below.

(1) Adoption of a rigid frame bridge design with an integrated superstructure and substructure in the bridge improves seismic performance and economy, while maintaining harmony with the urban landscape.

(2) Block precast steel structures are used for all main girders, piers, and footings, reducing assembly time at the site.

(3) JFE Steel's screw-type ground-penetrating steel pipe piles, "Tsubasa Pile" and "Micro-pile with Plural Wings," are used as foundation piles, enabling low-noise, low-vibration construction with no discharge of surplus soil. Since cementing is not used, the QCIB Method does not cause problems such as groundwater pollution or industrial waste.

(4) As the foundation connection method, steel footings are mounted directly on the foundation pile heads, reducing costs and shortening the work period.

(5) In parallel with the foundation work, the integral bridge is assembled as a unit in the smallest possible work occupancy area which avoids the intersection, minimizing the necessity of traffic lane restrictions.

(6) The construction procedure is as follows:

Step 1: The bridge, which was assembled in an integrated unit at the two sides enclosing the intersection, is lifted as a unit by air casters or a deck lifter on a self-propelled vehicle, moved in the direction of the intersection, and connected.

Step 2: At the same time, the steel footings of the bridge piers are inserted on the completed foundation piles and then joined with concrete to form an integral structure. This closing and joining work can be completed in roughly 4 h of a single night, greatly alleviating traffic restrictions at the intersection.

Step 3: After construction of the bridge over the intersection, the remaining bridge construction and embankment work are performed with no traffic lane restrictions.

Adoption of the QCIB Method is expected to shorten the site work time to approximately 4.5 months and reduce costs by approximately 10% in comparison with the conventional method.

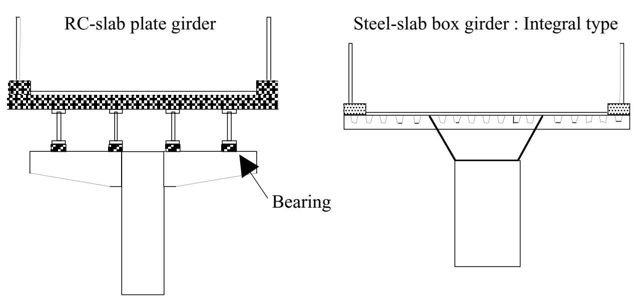
4. Outline of Main Structure and Construction Method

4.1 Integration of Bridge Superstructure and Substructure

In the bridge position, a steel-slab box girder integral type (or I-beam type) structure is used in place of the conventional RC-slab plate deck I-beam structure, as shown in **Fig. 2**, substantially reducing the dead weight of the superstructure. This weight reduction is also reflected in a cost reduction for piers and the foundation. The bridge height is reduced by integration of the superstructure and piers and by the lower girder profile made possible by using steel box girders. Consequently, the total bridge length is reduced, improving the economy of the bridge as a whole.

4.2 Integration of Bridge Piers and Footings

Block precast steel structures are used for all bridge piers and footings to save labor in site work. In particular, the piers and footings are integrated, as shown in **Fig. 3**, greatly reducing site work time. The steel footings are divided into blocks which are assembled at the



(a) Conventional structure (b) Proposed structure

Fig. 2 Superstructure of the bridge

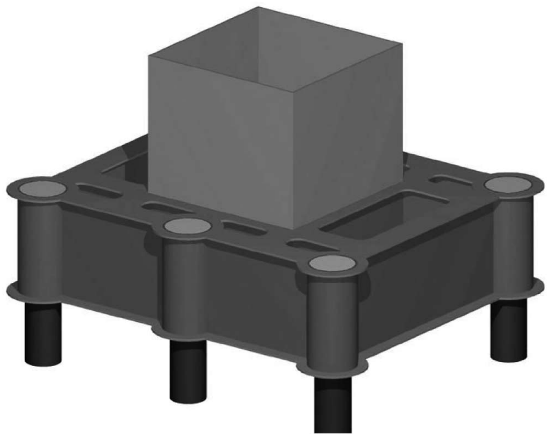


Fig. 3 Integral structure of footing and pile

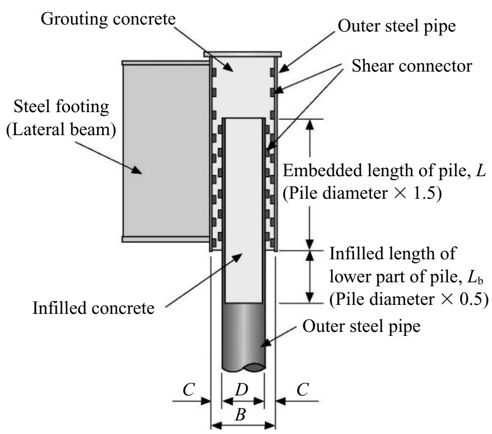


Fig. 4 Joint structure of footing and pile

site with bolts, allowing quick, easy execution of work even in restricted spaces. Moreover, because the steel footings are buried in the ground, the surplus soil produced by excavation at the site can be reused, and corrosion resistance is improved by backfilling with solidification treated soil or coating with concrete. In many cases, pile foundations are used in urban areas due to weak ground. Therefore, construction efficiency was improved by adopting the direct embedding method shown in **Fig. 4** in the joint structure between the steel footing and foundation piles.

4.3 Adoption of Screw-type Ground Penetrating Steel Pipe Piles

Tsubasa Pile and Micro-pile with Plural Wings are used as foundation piles. They enable low-noise, low-vibration pile driving with no discharge of surplus soil, and do not cause groundwater pollution and industrial waste problems because cementing is not used.

As a guideline for appropriate use of the two types, a bearing pile foundation using Tsubasa Pile (Pile diameter: 300 mm or larger, Shown in **Photos 1**, **2**) is adopted when the ground is extremely soft and the bearing stratum is also deep. Tsubasa Pile is a steel pipe pile with a wing-like toe plate at the leading end, which allows the end to penetrate the ground easily when the pile is rotated and provides a large bearing force at the pile end. In particular, costs can be reduced by taking advantage of the large bearing force of the pile end to reduce the number of piles.

As shown in **Fig. 5** and **Photo 3**, Tsubasa Pile penetrates the ground and roots in the bearing stratum when rotational force is applied to the top of the pile with an ordinary turning motor mounted on a 3-point pile driver. Bearing force is easily controlled, as the bearing stratum can be confirmed from the change in torque.

In driving Tsubasa Pile, a 3-point pile driver or full-circumference turning machine is used. However, considering the space restrictions which generally exist at construction sites, Micro-pile with Plural Wings, shown in **Photo 4**, is also used in some cases, depending on the ground conditions, because this type can be driven with small-scale equipment. (This pile was jointly developed by Konoike Construction Co., Ltd., JFE Steel, and Chiyoda Geotech Co., Ltd.) Micro-pile consists of a steel pipe pile with a series of 4 wings at different heights, which easily penetrates the ground when the pile is turned and give the pile a large bearing force. It was jointly developed with Public Works Research Institute as a pile for seismic strengthening work, and can be used in cramped spaces and in construction with raking piles.

The construction procedure with Micro-pile with Plural Wings is illustrated in **Fig. 6**. The procedure is summarized below.

(1) The pile is inserted under the pile-driving motor and brought to an erect position at the pile center point.

Photo 1 Screw pile, Tsubasa Pile

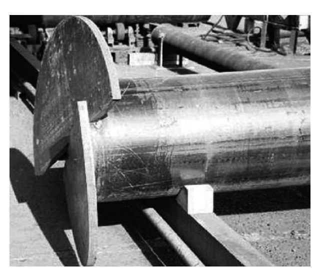


Photo 2 Toe of Tsubasa Pile

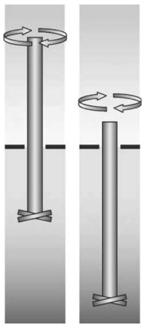


Fig. 5 Installation of Tsubasa Pile (Penetrate into ground like a screw)

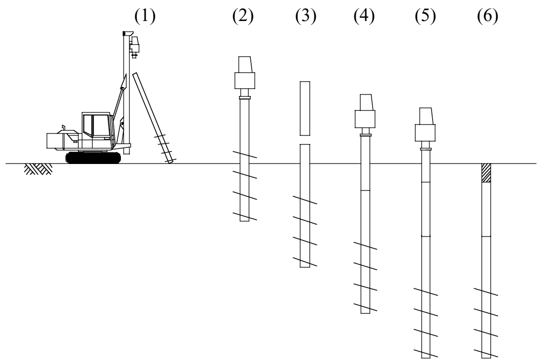


Fig. 6 Construction procedure of Micro-pile with Plural Wings

Photo 3 Construction of Tsubasa Pile using pile driver

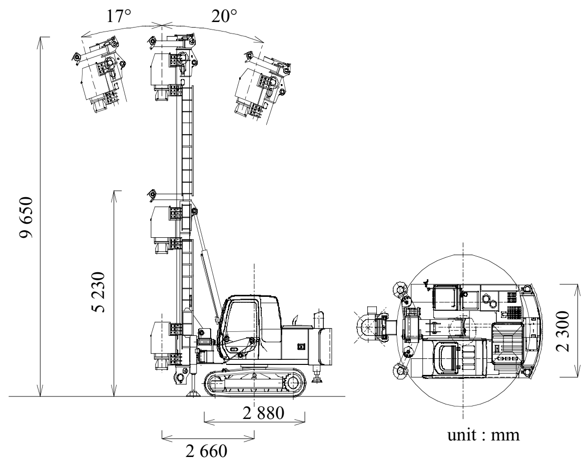


Fig. 7 Pile driver for Micro-pile with Plural Wings

Photo 4 Screw pile, “Micro-pile with Plural Wings”

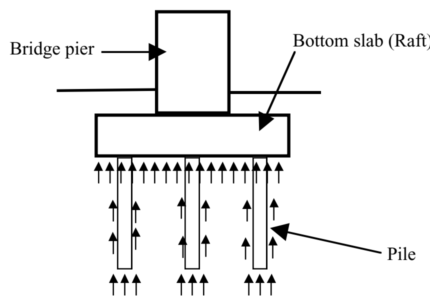


Fig. 8 Piled raft foundation

(2) After confirming perpendicularity, the pile is driven by turning.

(3) In case of continuous piles, the middle/upper piles are put in an erect position and welded to the preceding pile end.

(4), (5) The pile is driven to the specified depth using pincers, and driving is discontinued.

(6) The pincers are recovered, completing the driving procedure.

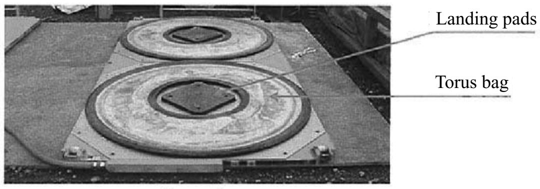
As a pile driver, the small-scale 3-point pile driving shown in **Fig. 7** is used. In addition to vertical piles, this machine is also capable of driving raked piles at angles of up to ±15°, and is suitable for projects where quick work is required at sites with limited yards.

Although this pile cannot be adopted in spread footings except with sandy ground (*N* value: 30 or higher) or clay ground (*N* value: 20 or higher) under the current Specifications for Highway Bridges, application in a piled raft foundation (**Fig. 8**) is being studied for cases where the ground is relatively good. The piled raft foundation is a type of joint-use foundation which can be considered an intermediate system between a pile foundation and spread footing. Since the number of piles can be significantly reduced in comparison with conventional group-pile foundations, it also has a potential to substantially reduce costs and construction time.

As this pile is also effective in preventing non-uniform subsidence, joint research with Public Works Research Institute is currently underway.

4.4 Air Caster

The air caster (**Photo 5**) is used to move the main bridge assembly in the QCIB Method. Based on a principle similar to that of the hovercraft, compressed air is



Two torus bag air caster (Photo shows torus bag side.)

Photo 5 Air caster

blown onto the floor surface below the air caster torus bags, forming a thin air film between bags and floor. This reduces the coefficient of friction between bags and floor to approximately 0.003, enabling easy movement. The specifications of the air caster (Type K60UHD) are shown below.

(1) Capacity: 534 kN/bag
(2) Internal pressure under maximum load: 34.5 N/cm^2
(3) Air consumption: 2.38 m^3/min
(4) Diameter: 1 524 mm
(5) Thickness (not in use): 70 mm
(6) Thickness (in use): 159 mm
(7) Lift: 89 mm
(8) Dead weight: 1 421 N

The JFE Group uses air casters to move hybrid caissons in the yard, and became the first in Japan to apply an air caster construction method to bridge construction at the Komasegawa Bridge (ordered by the Japan Highway Public Corp.), where it was used to move the structure 260 m. Although self-propelled vehicles are used in the conventional bridge movement, rails and heavy-duty trucks are necessary, and in some cases, the truck height and economy are problems. In comparison, the air caster method does not require rails, and the force necessary for movement is minimal because the air caster bags are set under the bridge support frame and the bridge is moved while floating on a cushion of compressed air. Thus, construction can be accomplished using extremely simple equipment (**Fig. 9**), provided sufficient surface accuracy (flatness) is secured in the area where air is to be blown.

The principle of the air caster method is as follows (**Fig. 10**):

(1) Before air is supplied, the load is supported by landing pads.
(2) When air supply begins, the air caster torus bags expand, forming a seal with the floor surface.
(3) As the air pressure increases further, air escapes slowly and uniformly from the clearances between the bags and the floor in balance with the load. The air film thickness at this time is around 0.1 mm, and the coefficient of friction decreases to 0.002–0.005.

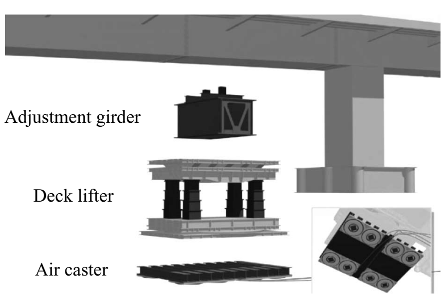


Fig. 9 Air caster and deck lifter

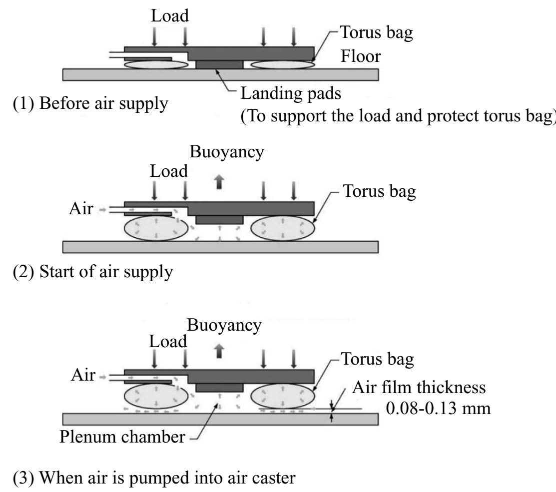


Fig. 10 Principle of air caster

4.5 Terre Armee Method

After construction of the intersection portion, the embankment section of the bridge approach is constructed by the prefabricated Terre Armee method or other suitable techniques. In the Terre Armee method, after the side wall material (concrete skin) is assembled, vertical fill which enhances the stability of the embankment as a whole is constructed by successively laying a reinforcing material called strip in the embankment material. This method has been used in Japan in 13 000 projects with a total area of approximately 6 million m^2 during the 30-year period since it was introduced in 1972, and its structural safety is excellent, being based on clearly defined design standards. In particular, studies of earthquake damage in the Hyogo-ken-Nanbu Earthquake and other earthquakes have confirmed that this method provides a high seismic performance necessary in urban areas. Because the Terre Armee wall is a soft structure which is capable of the following ground subsidence behavior, ground treatment is reduced. From the viewpoint of construction efficiency, it also has a number of advantageous features for quick construction in urban areas with numerous limiting conditions. For example, wall assembly and banking work can be executed almost simultaneously, member assembly and civil work can be performed inside the structure allowing the use of the fronting road. **Figure 11** shows an image (side elevation) of an embankment constructed by the Terre

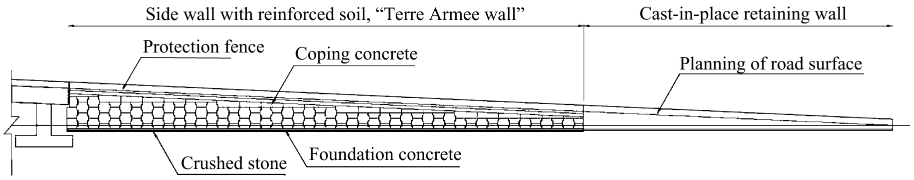


Fig. 11 Image of embankment by Terre Armee method

Armee method.

5. Summary

To complete bridge construction work in the shortest possible time, it is necessary to construct the foundation, substructure, and superstructure simultaneously in parallel. However, because the limiting conditions affecting construction differ depending on the site, the selection of the optimum construction equipment, method of assembling prefabricated blocks, and method of minimizing traffic restrictions must be determined on a case-by-case basis. Therefore, comprehensive management corresponding to site conditions is important, and a complete advance construction planning is desirable.

It is also important to reduce costs by applying new technologies. Because pile foundations can be constructed with Micro-pile with Plural Wings using a small-scale pile driver, this type of foundation is suitable for foundation construction on existing roadways. The piled raft foundation using this new pile substantially reduces the number of piles in comparison with the conventional group-pile foundation, and thus has the potential to greatly reduce costs and construction time. In fiscal year 2002, the JFE Group began a joint research project with Public Works Research Institute and expects to improve this method as a more rational design/construction technology.

Finally, to ensure sound construction of integral bridges, it is necessary to make the fullest possible use of the technical capabilities of the construction contractor, bridge maker, and construction equipment maker. From this viewpoint, interdisciplinary cooperation, in which individual engineers are not bound by the technologies in their own specialties, is essential for the future. The JFE Group intends to play a pioneering role in this field.

In conclusion, the authors wish to express their appreciation to people of Konoike Construction Co., Ltd. concerned for their cooperation in the joint development of piles.

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