Abstract

Moriguchi JCT which is under construction is the ramp connecting Hanshin Expressway Moriguchi Route with Kinki Expressway. Because the foundation of the ramp bridges are strictly limited in space due to the underground installation, the socket anchoring system was adopted instead of the conventional anchor frame system. This system is one of the methods to anchor the steel pier into the foundation and consists of steel pier with PBL and socket steel pipe. Main reinforcements of the foundation are arranged and in-situ concrete is filled between the steel pier and socket steel pipe and inside the steel pier.

This paper summarize a construction of the socket anchoring system adapted to the highway bridge for the first time. Although socket anchoring system is adopted by some railroad structures and few road structures.

Introduction

Moriguchi JCT connects Hanshin Expressway Moriguchi Route with Kinki Expressway (Figure-1). Moriguchi JCT will disperse the traffic concentrated in the center of Osaka city, prepare alternative route at the time of the accident or disaster, and mitigate congestion at local street by connecting Hanshin Expressway Moriguchi Route and Kinki Expressway.

Figure-1 Moriguchi JCT construction site

1 Hanhin Expressway Company Limited, Osaka, Japan
Moriguchi JCT is surrounded by Hanshin Expressway Moriguchi Route (about 40,000 cars/day), Kinki Expressway (about 90,000 cars/day), Osaka prefectural road No.2, National road No.1 (about 100,000 cars/day), and Osaka Monorail. These structures make construction space very narrow. Moreover, by widening the existing RC piers and RC slabs, construction of Moriguchi JCT is very difficult.

This paper reports the socket anchoring system adopted in order to widen the existing piers and slab in the narrow construction space.

1. Structure summary

The outline of the socket anchoring system is shown Figure-2. This system is one of the methods to anchor the steel pier into the foundation and consists of steel pier with PBL and socket steel pipe. Main reinforcements of the foundation are arranged and in-situ concrete is filled between the steel pier and socket steel pipe and inside of steel pier. The socket anchoring system can expectedly reduce the cost and construction period by omitting anchor frame which is used for traditional anchor system.

Figure-3 shows the general drawing of pier AP3 using socket anchoring system. As shown in the section of the superstructure in Figure-3, we adopt rigid connection of new and existing concrete slab, and remove longitudinal joint from the viewpoint of easy maintenance, running comfortability. Therefore new pier foundation has to be placed in the same section of the existing pier foundation, and also connected rigidly with it.

However, if we place in the same section of the existing pier foundation, the AP3 pier is interfered underground installation, waterway and road, and AP3 pier foundation is limited in its structural size (Figure-4).
Table-1 compares three types of the foundation and shows that socket anchoring system is the most economical and able to mitigate the influence to the crossing road of the AP3 pier.

<table>
<thead>
<tr>
<th>Pier</th>
<th>RC pier</th>
<th>RC pier</th>
<th>Steel pier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundation</td>
<td>Caisson foundation (φ=5m)</td>
<td>Cast-in-situ concrete piles (φ=3m×2)</td>
<td>Caisson foundation (φ=4m)</td>
</tr>
<tr>
<td>Underground installation</td>
<td>Transfer</td>
<td>Not transfer</td>
<td>Not transfer</td>
</tr>
<tr>
<td>Traffic impact</td>
<td>Large</td>
<td>Very large</td>
<td>Small</td>
</tr>
<tr>
<td>Construction period</td>
<td>About 12 months</td>
<td>About 4.1 months</td>
<td>About 7.5 months</td>
</tr>
<tr>
<td>Cost (compared with ③)</td>
<td>2.3</td>
<td>1.5</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Table-1 AP3 pier foundation form comparison

Finally, socket anchoring system was chosen, however, there are not so many practical structures, just some for railroad and a few for road bridges, and Kosaka viaduct\(^1\) of the Ministry of Land, Infrastructure Transport and Tourism Shikoku Regional Development Bureau is the only for the large-scale load bridge. Thus Moriguchi is the first adoption for the expressway.

2. Design summary

Figure-5 shows the design flow of the socket anchoring system. "Design Standards for
Railway Structures and Commentary\textsuperscript{2})\textsuperscript{n} and the Kosaka viaduct design documents were referred for the design policy this time.

- **Pier design**
- **Pier foundation (caisson) design**

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**Design of connection**

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**Determination of structure**
- The plug length of the steel pier
- Socket steel pipe: diameter, thickness
- PBL: thickness, length, hole diameter
- Concrete: compression strength

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**Checking of ultimate limit state** (L2 earthquake equivalency)

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**Checking of ultimate strength**

\[
\begin{align*}
\text{Connection} (M_{ud}) & > \text{Pier basement} (M_u) \times 1.4 \\
\text{PBL} (M_{ud}) & > \text{Pier basement} (M_u)
\end{align*}
\]

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Ma: Bending moment of pier base when a steel member reached the allowable strain ($\varepsilon_a = 5\varepsilon_y$), Mu: Bending moment when the caisson reached ultimate strength

**Figure-5 Design flow of socket anchoring system**

In this design policy, the collapse of the pier correspond the ultimate state of the steel pier basement due to the plasticizing and following conditions need to be provided for appropriate collapse.

Steel pier < Foundation (open caisson) < Socket anchoring system

And the bending strength of socket anchoring system has to be more than 1.4 times of the bending strength of steel pier basement and also more than ultimate bending strength of foundation (open caisson).

Here, the design bending strength of socket anchoring system is to be given using the formula of “Design Standards for Railway Structures and Commentary”. Figure-6 shows the load model of the socket anchoring system. In this calculating formula, It is supposed that couple of forces of bearing pressure between the steel pier and socket steel pipe and couple of forces of frictional forces between steel pier and filling concrete resists the bending moment and shear force to act on steel pier. The bending strength ($M_{ud}$) of the connection can be obtained in the next formula by solving a balance moment shown in Figure-6.
\[ M_{ud} = T \left( \frac{2\sqrt{2}}{\pi} \right) d - \frac{L \cdot P^2}{3(2P - Q)} + \frac{L(5P - 2Q)}{3(2P - Q)} \]  \hspace{1cm} (1)

Here,

- \( M_{ud} \): The bending strength of socket connection,
- \( T \): The maximum resultant frictional force to act on a steel pier,
- \( P \): The maximum resultant bearing pressure to act on a steel pier,
- \( Q \): The shear force of socket connection,
- \( d \): Outer diameter of steel pier,
- \( L \): The plug length to a socket steel pipe of the steel pier.

**Figure-6 Load model of the socket anchoring system**

Inside of the socket steel pipe, shear connector (D13 reinforcement) was provided for the strength improvement which was shown in the past experiment[3, 4]. In addition, six PBLs (perfobond ribs) were adopted and welded on the outside of the steel pier for the safer structure. Figure-7 shows the load model of shear connector by PBL, and its strength was evaluated by following equation.

\[ M_{pbl} = \sum_{i=1}^{n} m \cdot P_{pbl} \cdot h_r \cdot \cos \theta_r \]  \hspace{1cm} (2)

Here,

- \( M_{pbl} \): Bending strength of PBL,
- \( P_{pbl} \): Shear strength per one hole of PBL,
- \( \theta_r \): Angle of PBL arrangement,
- \( m \): The hole number per one plate,
- \( h_r \): Distance from the steel pier section center to hole center.

**Figure-7 Load model of shear connector by PBL**
The plug length of the steel pier into the caisson and the outer diameter of socket steel pipe were determined as follow.

- The plug length of the steel pier: \( L \) (plug length) \( \geq 1.5d \) (outer diameter of steel pier) in accordance with “Design Standards for Railway Structures and Commentary”
- The outer diameter of socket steel pipe = Outer diameter of the caisson. The socket steel pipe thickness was determined concerning the ultimate strength and extra 1mm was added in consideration of corrosion.

Figure-8 shows the detail of socket anchoring system of AP3. Socket steel pipe is \( D = 4,000 \text{mm} \) in outer diameter, and steel pier is \( d = 1,600 \text{mm} \) in outer diameter, thus the ratio of them is \( D/d = 2.5 \), which is in the range of \( D/d = 1.47 \sim 3 \) indicated in the past experiments \(^3\), \(^4\).

![Diagram of socket anchoring system]

**Figure-8  Detail of socket anchoring system**

### 3. Construction summary

Figure-9 and Photo-1～6 show construction steps of socket anchoring system.

【STEP1】First, the steel sheet piles for the protection of adjacent structures was constructed, four lots of open caisson were penetrated into the ground by oil jacks. Then, quarterly divided socket steel pipe in which displacement preventing reinforcement is welded in the factory were erected by the rough terrain crane on the top slab of the open caisson. After welding anti-distortion materials, each parts of the socket steel pipe were welded to each other in the construction site. Then the socket steel pipe and open caisson was penetrated to a predetermined position.
【STEP2】Top slab of the caisson was constructed and then the steel pier was erected onto the top slab. During erection of the pier, the highway Moriguchi Route was closed.

【STEP3】Concrete was pouring in the gap between the steel piers and socket steel pipe first, which integrated the both members, and then inside the steel pier. Finally, the steel pier's foot protection was constructed around it in the extent of underground level. The temporary steel pipe which was upper part (t=9mm part) of the socket steel pipe, was removed and the ground was backfilled around the pier.
Conclusions

Because the foundation of Moriguchi junction pier AP3 was strictly limited in space due to the underground installation and also surrounding general road, the socket anchoring system was adopted for rigid connection of steel pier and caisson foundation instead of the conventional anchor frame system.

This structure which consists of socket steel pipe, PBL, steel pier and concrete is much compact and smaller than anchor frame, and thus it can make the foundation smaller and more economical. Because there is not any erection works of anchor frame in the caisson’s top slab with crowded reinforcement arrangement, construction of the socket anchoring system is much simpler and faster in terms of site works.

As of now the socket anchoring system can be adopted when the ratio of outer diameter of the socket steel pipe to the one of the steel pier is in the range of value indicated in the past experiments. However, this will be still effective and beneficial structure in the future especially in the case of limited space and conditions.

References

2) Railway Technical Research Institute :Design Standards for Railway Structures and Commentary (Steel-Concrete Hybrid Structures),2012-2
3) Shin-ichiro NOZAWA , Masanori KINOSHITA, Daisuke TSUKISHIMA and Tadayoshi ISHIBASHI: Ultimate Strength of Sleeve Joint between Concrete-Filled Circular Steel Pipes with Shear Connector, Proceedings of JSCE 634, 71-89, 1999-11-20