OUR STRATEGY TO CONSTRUCT LONG SPAN BRIDGES ON OCEA

- Presentation on Performances and Technical Challenges in Our Company for Long Span Bridges Constructing Across Ocean-

Hirokazu Miyamoto
Manager
Department of International
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Eight-Japan Engineering Consultants Inc. (EJEC)
Profile of Hirokazu MIYAMOTO

Professional Engineer (Japan) in Civil Engineering Steel & Concrete), and Soil & Foundation

Master of Civil Engineering, Kumamoto University, Japan, in 1986
Experience of Consultant for 30 years

Main Projects:

**In Japan**
- The Planning and Design the Sub-Structures on Kurushima Bridge and Tatara Bridge of Honshu-Sikoku Bridge Authority
- The Detail Design on Viaducts Design in Tokyo metropolitan outer loop highway Interchanges
- Connecting remote Island Project

**In Over Sea**
- Technical transfer project of JICA in East Africa
- Japan ODA Loan project in Myanmar
1. Introduction our performances on long span bridges Design

2. New technology in the design of Gosyonoura suspension bridge planned after Honshu-Shikoku Bridge Project

3. Our Technical challenges and solutions of Irabu Bridge constructed at subtropical region in Japan
1. Introduction of our performances on long span bridges construction across sea

A-Route

D-Route

E-Route

Eight-Japan Engineering Consultants Inc. (EJEC)
<table>
<thead>
<tr>
<th>Bridge Name</th>
<th>Structure</th>
<th>Feature, our performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shima maruyama Bridge</td>
<td>PC Cable Stayed Bridge (L=2@228m)</td>
<td>In that time of the design (1986), this had one of largest span in Japan</td>
</tr>
<tr>
<td>Uchinada Bridge</td>
<td>PC Cable Stayed Bridge (L=82+180+82m)</td>
<td>A design concept considering salt damage in concrete shape was introduced (2001)</td>
</tr>
<tr>
<td>Torigai-Ninnaji Bridge</td>
<td>Steel Cable Stayed Bridge (L=187.5+200m)</td>
<td>Multi fan type used with the largest strand in the world at the design (1980)</td>
</tr>
<tr>
<td>Yumesshima-Maishima Bridge</td>
<td>Steel Arch Bridge (L=410m)</td>
<td>The Largest Floating turning movable bridge (1992)</td>
</tr>
<tr>
<td>Totsui Bridge</td>
<td>Nielsen-Lohse Bridge (L=207.5m)</td>
<td>Landscape design (1994)</td>
</tr>
<tr>
<td>Kansai International Airport Bridge</td>
<td>Steel Viaduct (Max span L=150m)</td>
<td>Developed the design method on (1986)</td>
</tr>
<tr>
<td>Sky Gate Bridge R</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irabu Bridge</td>
<td>Steel &amp; PC Box girder</td>
<td>Construction in sub tropical Region, refer 3.</td>
</tr>
<tr>
<td>Bridge Name</td>
<td>Structure</td>
<td>Feature, our performance</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>-----------------------------------------------</td>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>Great Seto Bridge</td>
<td>Suspension Bridge (1,538+1,643m)</td>
<td>Out lone design on Hitsuishi Island bridge Design steel laying caisson (1976)</td>
</tr>
<tr>
<td>Akashi-Kaikyou Bridge</td>
<td>Honshyu-Shikoku Bridge Project L=3,910(center 1,900m)</td>
<td>Established seismic design method on rigid body foundation(1986)</td>
</tr>
<tr>
<td>Kurushima Bridge</td>
<td>960+1,515+1,570m</td>
<td>Plan, design substructures for main tower and anchorages, developing seismic design</td>
</tr>
<tr>
<td>Tatara Bridge</td>
<td>Cable stayed Bridge</td>
<td>We concentrated on substructure design</td>
</tr>
<tr>
<td>Gosyonoura Bridge</td>
<td>Suspension Bridge (L=842, center 620m)</td>
<td>Post Honshu-Shikoku project, refer 2.</td>
</tr>
<tr>
<td>Trans-Tokyo Bar Highway (Tokyo Bay-Aqua line)</td>
<td>Shield Tunnel &amp; Steel Box Girder</td>
<td>Design of an artificial island for construction of shield tunnel(1985), Study on multi span continuous bridge for the approach bridge(1989)</td>
</tr>
</tbody>
</table>
2. A Suspension Bridge designed after Honshu-Shikoku Bridge Project

Gosyonoura Suspension Bridge for connecting remote island in Kumamoto prefecture

(1) Bridge Length : \( L = 247 + 620 + 75 = 942 \) m

(2) Approach Bridge-1 : Five span continuous Steel Box Girder

(3) Main Bridge : Single Span Suspension Bridge (620m)

(4) Approach Bridge-2 : Single span Steel Box Girder

Design duration : from 2.2001 to 2.2004
2.1 Study on Design Earthquake with Fault Model

The Bridge Site

Design Earthquake Ground Motion for This Project with Fault Model

Kumamoto City

Beppu-Shimabara Trough

Futagawa-Hinagu Fault

Yatsushiro Seabed fault zone

Design Earthquake for this project

Natural Period (sec)

Acceleration Response Spectrum (cm/s/s)

Specification type II

h=5%
2.2 Remarkable we had proposed in this Project

① Steel Pipe and Concrete Composite Tower

② New Concept on Stiffened Box Girder without any stabilizer

③ Developed Tunnel type Anchorage

$V_{10}=39 \text{ m/s}$
2.3 Developed Tunnel Type Anchorage

(1) Profile of Tunnel Anchorage

1. Excavate tunnel using incline system
2. Widen bottom tunnel to store anchor girder, and to increase pulling resistance by shear key
3. Install anchor girder and frame to fix cable
4. Fill concrete
(2) Stability of Tunnel Anchorage

\[
F_s = \frac{W \sin \theta + \mu \cdot W \cos \theta + C_B \cdot A}{T} \geq 2.0 \quad -(1)
\]

\[
F_s' = \frac{C_B \cdot A}{T - (W \cdot \sin \theta + \mu \cdot W \cdot \cos \theta)} \geq 2.0 \quad -(2)
\]

\( W_R \); Own Weigh of Tunnel (kN)

\( W_c \); Weigh of Rock with tunnel (kN)

\( C_B \); Cohesion at bottom and side of Tunnel (kN/m²)

\( A \); The area of supposed fracture surface (m²)

\( \mu \); Friction Coefficient at Tunnel Bottom

\( \theta \); Inclination angle of tunnel (°)

\( T \); Cable Tension (kN)

\( \tan \theta \); Reduction of soil strength in consideration of the loosening of the soil by digging

Cable Tension

Assumed design fracture surface (Cylindrical)
Comparison with the conventional Type

<table>
<thead>
<tr>
<th></th>
<th>4A Anchorage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Upper Half Widening</strong></td>
<td></td>
</tr>
<tr>
<td>Profile (conventional method)</td>
<td><img src="profile_upper_conventional.png" alt="Profile Diagram" /></td>
</tr>
<tr>
<td>Safety Rate</td>
<td>$F_s = 2.50$</td>
</tr>
<tr>
<td>Excavation Volume</td>
<td>1.00</td>
</tr>
</tbody>
</table>

| **Lower Half Widening** |              |
| Profile (Proposal)     | ![Profile Diagram](profile_lower_proposal.png) |
| Safety Rate            | $F_s = 2.45$ |
| Excavation Volume      | 0.91         |

**Ground stress at Lodging twice design force**

**Displace of Anchorage (mm)**

<table>
<thead>
<tr>
<th>Design FORCE $T$</th>
<th>2 × $T$</th>
<th>3 × $T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displace</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper Half Widening</td>
<td>![Displace Upper.png]</td>
<td></td>
</tr>
<tr>
<td>Lower Half Widening</td>
<td>![Displace Lower.png]</td>
<td></td>
</tr>
</tbody>
</table>

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3-D F.E.M Analysis on Tunnel Type Anchorage

Displacement

12.0 m
3.4 m
3-D F.E.M Analysis on Tunnel Type Anchorage (Mutual interference effect of proximity tunnel)

- Initial stress analysis
- Tunnel Excavation
- Fill concrete into Tunnel Loading Cable Tension
- Excavation of road Tunnel Above Tunnel Anchorage
3. Technical challenges and solutions of Irabu Bridge constructed at Subtropical region,

Location of Irabu Bridge

- 1800 km from Tokyo
- 300 km from Okinawa main island
- 380 km from Taiwan
3.1 Bridge Structure Summary

Irabu Bridge Total Length is 3,540 m

(1) Miyako Island side: 32-span continuous PC box girder bridges
   L=2,185 m, Average span length = 70 m
(2) Main Course: three-span continuous steel box girder bridge
   L=320 m =120 m +180 m +120 m
(3) Iranu Island side: 14-span continuous PC box girder bridges
   L=935 m, Average span = 70 m
(4) Total number of substructure 50 nos, number of steel pile is about 800

Construction Cost about 360 million US dollar
3.2 Bridge Construction Summary

**Implementation Policy on The Project**

**Policy-1:** In order to maintain the rich natural conditions of the construction site, the project shall reduce the impact to the natural environment.

**Policy-2:** In order to create new tourism resources, this project shall realize bridges and highway environmental own high added value.

**Policy 3:** We shall propose the excellent durability minimum maintenance bridges taking into importance of maintenance for public facilities.

**Policy 4:** We shall reduce more life cycle cost in this project by making positive efforts to use the latest technology and construction method into this project.
Technical Issues in Construction

1. Aerodynamic Design
   Design wind velocity $U_{33}=82.2$ m/s
   In Mainland of Japan usually 40 – 60 m/s

2. Durability Design for Strong Splash including highly concentrated Salt
   Exposed to constantly warm moist strong sea breeze

3. Construction Managing for Steel Pile foundation driven into Unique Ground

Irabu Bridge was awarded the Tanaka Award in 2015 for following reason

- This bridge has been constructed in one of the severest environments in Japan with subtropical heat and humidity, strong wind, and frequent typhoon attacks.

- The design and construction to withstand this severe environment will contribute significantly to the development of future bridge technology.
Tanaka Award was established to honor Dr. Tanaka for his pioneering contribution to bridge and structural engineering in 1966.

Nowadays the award is counted as one of prestigious and authoritative awards in the civil engineering field in every year.

The award is made in the three categories:

1. Outstanding Achievement
2. Excellence in Research Paper
3. Excellence in Bridge Design and Construction
Steel Box Girder type was chosen from many type bridge in considering following conditions;

i. Aerodynamic Stability  
   (peak gust 87m/s)

ii. Reduce Maintenance works in future

ii. Safety during erection works  
   (this area has heavy wind more than 10m/sec in every day excluding a short season)

It was the first experience in Japan to erect a long span bridge on sea under such sever natural conditions.
Flat shape box girder having any projections

1) Realization of high wind stability without any additional aerodynamic stabilizer
   - the wind velocity for nominal vibration > 82.2 m/sec
   - the wind velocity for divergent vibration > 108.5 m/sec

2) Reduction of salt adhesion amount
   - Minimization of surface area
   - Rinsing adhesion salinity on surface by rain

3) Improve a workability for welding joint in the situ

These implementation requires high construction techniques of Japan such as full circumferential welding in the situ and marine erection, etc.
Construction Procedure of Main Course Steel Bridge

① Main girder transportation from Japan Mainland

② Preparation at near site

③ Transportation to the site

④ Erection at the site by floating crane

⑤ Circumference welding of box girder in the situ
(2) Continuous PC Box Girder Bridges

Continuous PC box girder by travelling erection girder is one of most popular bridge type in remote islands connecting project in Okinawa prefecture.

New technologies introduced into this project in order to more enhance durability for soil damage and reduce maintenance are follows;

(1) Post sliding construction method to achieve multi-continuous bridge
(2) Antirust pc cable and re-bar coated by epoxy resin
(3) Apply Fly Ash Cement which has lower permeability
(4) Establish Monitoring system to research chloride ion penetration into concrete
Various Countermeasures for Chloride

(1) Post sliding method to send back bearing deformation

① Bearing deformation due to Shrinkage and Creep

② Send back

(2) Epoxy resin-coat

① Coated Reinforce

② Coated PC cable

(a) Coated wire

(b) PE cover + Coated wire
(3) Fly Ash Cement

- **Expected Effects**
  - Improvement of water-tightness and durability
  - Improvement of salt penetration resistance
  - Inhibition of alkali aggregate reaction
  - Suppression of the temperature rise due to hydration heat
  - Improvement of consistency, and Decrease unit quantity of water
  - Reduction of shrinkage

- **Disadvantage**
  - *Slow exertion of strength*
    Use to only substructure in this project

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Survey Result on Existing Bridges used normal portland cement in Okinawa

Based on the experience in this project, Fly Ash cement Concrete will become a standard in Okinawa Region
Monitoring Plan on Chloride concentration in Concrete

CAESAR (Center for Advanced Engineering Structural Assessment and Research) and Okinawa prefecture are monitoring Chloride Concentration jointly. This survey results will help a maintenance of this bridge, and is hoped to advance more effective chloride countermeasure design.

Concrete coring plan for monitoring

Concrete spacemen for exposure test
1. What are Issues for Driven Pipe Pile Foundation?

(1) The Characteristic of the bearing stratum

- The bearing stratum for pile foundation is called ‘Shimajiri Formation’ this consists of soft mad rock and sand rock, and accumulated from Pliocene epoch to Pleistocene epoch, about 3 million years ago.
- A concretion of these rocks is very low, so easily to pulverize at dry condition. Especially particle distribution size of sand layer is very unity.
1. What are Issues for Driven Pipe Pile Foundation?

(2) Issue of Open-End Steel Pipe Pile embedded into SAND layer

- We have some studies and experiences for driven pile foundation supported by this mad stratum, but have never experienced for this sand rock stratum.
- We worried that workability and characteristics of bearing capacity on open-end steel pile embedded into ‘Shimajiri Formation’ sand stratum, that why are follows;
  1. Insufficient a effect of closed tip ⇒ How we can get enough bearing capacity corresponding to strength of the Rock
  2. Difficulty of judgment to stop the driving operation in situ ⇒ As large penetration amount at each impact continue, it will be very difficult to judge finishing timing at site work

(a) Bearing capacity mechanism at tip and Effect of the end closed tip

(b) The driven operation

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2. Loading Test & Development

(1) Loading Test

Pile Driven by Hydraulic Hammer

Static Loading Test

Rapid Loading Test

Hydraulic pile hammer

Mad Rock

Rebound &
Penetration (mm)

embedded depth of pile into bearing stratum (m)

Rebound

Penetration

Sand Rock

Rebound &
Penetration (mm)

embedded depth of pile into bearing stratum (m)

$R_u = 7,687$ (kN)
$q_d = 6,439$ (kN/m$^2$)

$R_u = 45,604$ (kN)
$q_d = 5,652$ (kN/m$^2$)
(2) Our Study and Solutions

- Establish an **arc ribs steel pipe pile** aimed at the high effects of end closed
- **Strategic application** of reinforcing structure at tip in accordance with **ground condition at each foundation**
- In order to realize the above, re-check existing geological survey results carefully
- Evaluating a bearing capacity at pile, and Establishing a management criteria for finishing driving operation in situ

![Diagram of reinforcing band and arc ribs steel pipe pile]

- **Sand Rock**
- **Alternate Mad and Sand Rock**

- **Standard type with reinforcing band**
- **Arc ribs steel pipe pile**
- **Standard type without reinforcing band**

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### (3) Results

#### Criteria for Finishing Driving Operation

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>Bearing Stratum</th>
<th>Type of Pole</th>
<th>Target Embedded Depth</th>
<th>Loading Test qd (kN/m²) at pile tip</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>CATEGORY-1</td>
<td>Mad Rock</td>
<td>Normal with Band</td>
<td>2.0m (L/D=2)</td>
<td>6,439</td>
<td>There are obstacle in the intermediate layer</td>
</tr>
<tr>
<td>CATEGORY-2</td>
<td>Sand Rock</td>
<td>Normal with Band</td>
<td>5.0m (L/D=5)</td>
<td>(8,021)</td>
<td></td>
</tr>
<tr>
<td>CATEGORY-3</td>
<td>Sand Rock</td>
<td>Arc Rib Pile</td>
<td>2.0m (L/D=2)</td>
<td>7.996</td>
<td>Expect enough Effect of end Closed</td>
</tr>
<tr>
<td>CATEGORY-4</td>
<td>Mad &amp; Sand Mix</td>
<td>Normal without Band</td>
<td>3.0m (L/D=3)</td>
<td>8,021</td>
<td></td>
</tr>
</tbody>
</table>

#### Results of Pile Driving Works

- **Normal Pile with Reinforcing Band (P18)**
- **Steel pile with Circular Rib (P29)**
- **Normal Pile with Reinforcing Band (P24)**
- **Normal Pile without Reinforcing Band (P15)**
Thank you for your kind attention

Please contact me if there are any question!

Hirokazu Miyamoto
Department of International
Eight-Japan Engineering Consultants Inc. (EJEC)
E-mail: miyamoto-hi@ej-hds.co.jp