Honshu-Shikoku Bridge Project
Construction, Maintenance and Socioeconomic Impact

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1. Introduction of the Honshu Shikoku Bridges
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1. Introduction to the Honshu Shikoku Bridges
Honshu-Shikoku Bridges

- Kobe-Naruto Route (89 km)
- Onomichi-Imabari Route (59 km)
- Kojima-Sakaide Route (Highway 37 km, Railway 32 km)
- Akashi Kaikyo Br.
- Seto-Ohashi
- Ikuchi Br.
- Innoshima Br.
- Tatara Br.
- Kurushima Kaikyo Br.s

Honshu

Shikoku
### Honshu-Shikoku Bridges

<table>
<thead>
<tr>
<th></th>
<th>Nishi-Seto</th>
<th>Seto-Chuo</th>
<th>Kobe-Awaji-Naruto</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Expressway</strong></td>
<td><strong>80km/h</strong></td>
<td><strong>100km/h</strong></td>
<td><strong>100km/h</strong></td>
</tr>
<tr>
<td><strong>Design speed</strong></td>
<td><strong>4, 2</strong></td>
<td><strong>4</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Lanes</strong></td>
<td><strong>4, 2</strong></td>
<td><strong>4</strong></td>
<td><strong>6, 4</strong></td>
</tr>
<tr>
<td><strong>Railway</strong></td>
<td><strong>-</strong></td>
<td><strong>Ordinary &amp; (Shinkansen)</strong></td>
<td><strong>-</strong></td>
</tr>
<tr>
<td><strong>Length (Expressway)</strong></td>
<td><strong>59km</strong></td>
<td><strong>37km</strong></td>
<td><strong>89km</strong></td>
</tr>
</tbody>
</table>

*Shinkansen can be loaded in the future.*
Honshu- Shikoku Bridge Project

• In 1955, First site investigation was begun.
• In 1967, the Japan Society of Civil Engineers submitted the Final Report.
• The Honshu-Shikoku Bridge Project was adopted in New National Land Development Program in 1969
• Construction started in 1975.
• Three Routes were opened in 1999.
• HSBA was established in 1970 and became a private enterprise HSBE Co., Ltd. in 2005.
2. Technical Features in the Construction Stage
Technology of Superstructure

- Design Standard
- Wind Effect for Bridge
- High strength Cable Wire
- Railway Movement Joint System
- Cable Anti Corrosion System
- Self Propelling Barge for Girder Erection
- Cable Stayed Bridge
REQUIRED TECHNOLOGY
(Super-Structure)

- International Waterway (1500m + extra space)
- Strong Wind (80 m/s)
- Very Long Span (1990 m)
- Satisfactory Aerodynamic Performance
- High Strength Wire
- New Anti-Corrosion Method for Cable
Wind Resistant Design

Wind Tunnel Test
Akashi Kaikyo Bridge
High tensile wire

Development of New Materials
High tensile wire

Double Cable

Single Cable

Reduction of Steel Weight 27,000 ton
Seto-Ohashi (highway and railway)
Superstructure Construction under Severe Natural Conditions

Lifting Girders Directly below Erection Points

By Self-propelled Barge
Self-propelling Barge

Kurushima Kaikyo Bridge
Cable Stayed Bridge

Buckling Test for the Girder
Cantilever Erection of Cable Stayed Bridge
Practical Bridge Shaking Test
Buckling tests for 1/50 Model
Cantilever erection of the Girder
Practical shaking test
Technology of Substructure

• Design Standard
• Aseismic Design
• Laying Down Caisson Method
• Scoring Protection
• Under water Non-Disintegration Concrete
REQUIRED TECHNOLOGY
(Sub-Structure)

Deep Water (60 m at pier site)
Rapid Tidal Current (4.0 m/s at pier site)
Geology (semi-consolidated gravel)
Seismic Design (M 8.5)

Huge Scale Sub-Structure (70 m – 80 m)

Laying-Down Caisson Method
Underwater Non-disintegration Concrete
Scour Protection
Aseismic Design for Major Earthquake
SEISMIC DESIGN

Input Seismic Excitation

- Earthquake occurring with recurrent cycle of 150 years
- Earthquake of M 8.5 with distance of 150km

Maximum Acceleration of 800 gal

Kobe Earthquake (1995.1.17) Distance of within 3km M7.2
Standard acceleration spectrum

- \( h = 0.05 \)
- \( M = 8.5 \)
- \( \Delta = 150 \text{ km} \)
- \( T_R = 150 \text{ years} \)

Graph shows acceleration response spectrum with different curves indicating various conditions.
Surveys of the Seabed

- To Investigate for Characteristics of Supporting Layer
- Undisturbed Sample
- Large-diameter Core Sampling Technology

30cm Dia.
Sinking Steel Caisson

Laying-Down Caisson Method
Scour Protection

Akashi Kaikyo Bridge

Tidal Current 4.0 m/s

without scour protection

with scour protection
UNDERWATER NON-DISINTEGRATION CONCRETE

REQUIREMENT

Non-integration in Water  △ Viscosity Admixture
Self-Leveling ( △ 56 m )  △ Fluidity Admixture

Large-Volume Casting Work

Total amount  2P Caisson 259,000 m³
              3P Caisson 232,000 m³
Concrete Plant Barge (25,000t)
Akashi Kaikyo Bridge after the earthquake
Distribution of Faults around Bridge
Deformation of bridge

Kobe-side

Awaji-side

Side View

Plan (at foundation level)

1A 2P 3P 4A

Before

After

960m 1,990.8m 960.3m

960m 1,990m 960m

3,910m

0.2m 0.3m 0.8m

0.1m 0.1m 0.2m 0.2m 0.8m

1.1m 1.1m
3. Technical Development of Maintenance
Characters of H-S Bridges

- Large scale structures of 17 long span bridges.
- Long period maintenance more than 200 years.
- Environmental condition is severe.
- New material and structures are used.
- Flexible structure
Inspection of Long-Span Bridges

• Objective
  – Early discovery of damages
  – Appraise the conditions of the structure

• Category
  – Regular Inspection
    • Patrol Inspection
    • Basic Inspection
    • Precise Inspection
  – Nonscheduled Inspection
    • Extraordinary Inspection
    • Special Inspection
Equipment for Maintenance

- Cable Work Cages
- Outside Work Gantry
- Tower Maintenance Gondola
- Inside Work Gantry
Example of Painting system (lower spec is for the central route)

**Painting composition**

- **25 µm**: Polyurethane: Excellent weather-proofing
- **30 µm**: Epoxy resin: Role of adhesive
- **120 µm (60 µm x 2)**: Epoxy resin: Excellent water-proof and inorganic zinc protection
- **75 µm**: Inorganic zinc: Excellent electrochemical corrosion protection

**Steel**
Paint film deterioration forecast

Painting composition

- 25 µm
- 30 µm
- 120 µm
- 75 µm
- steel

Paint film deterioration curve

- Limit control level (red line)
- Top & Middle coat
- Under coat
- Period for repainting

Thickness of paint film (µm) vs. Passage years

0 5 10 15 20 25 30 35
0 50 100 150 200 250 300 350
Dry-air Sending System in the Box Girder

1～4: Measurement Points of Relative Humidity
Corrosion Protection System for Conventional Main Cable

Section of wrapping system

Wrapping wire (round)
Coating
Paste

Galvanized wire

Past

Coating

Wrapping wire

Galvanized wire

Remaining water

Steam
Dry-air Injection System of the Akashi Kaikyo Bridge

A: Control panel
B: Filter
C: Dehumidifier
D: Roots blower
E: Discharge silencer
F: Cooler

Air Injection Pipe
Air Exhaust Cover
Air Injection Cover
Main Cable
Tower
Stiffening Girder
Dry-Air Injection System

Air-injection Cover
Results of Critical Humidity Test with Varying Salinity
Corrosion Protection System

Akashi Kaikyo Bridge

Kurushima Kaikyo Bridge

Coating
Rubber wrapping
Liquid rubber primer
Adhesive
Round wire wrapping
Galvanized wire

Soft fluororesin coating
Galvanized wire
S-shaped wrapping wire
Enlarged

3 mm
7 mm
Electro-deposit Protection Method for Skin Plate of Steel Caisson Foundation
Corrosion status of skin plate of steel caisson Foundation

Maximum $\phi$ 50mm $\times$ depth 10mm
Principle of Electro-Deposit System
Progress of Adhesion Film Formation

Before scale removal

After scale removal

15 months after charge

Before charging
Maintenance Procedure for Concrete Structures

- Inspection
- Investigation
- Prediction of deterioration
- Estimation, Judgement
- Selection of Measures
- Implement Measures
Prediction
(Chloride Ion Penetration)

1A anchorage in Ohnaruto Bridge
Other Engineering Developments

- Non-destructive inspection of suspender ropes
- Impregnating paints for prevention of concrete-structure deterioration
- Painting robot
Non-destructive Inspection of Suspender Ropes
-Main Flux Method-
Apparatus Construction
Relationship between decrease in Cross-sectional Area and Strength decrease Rate (Ohnaruto Br.)

\[ Y = 5.9765 \cdot X^{0.6145} \]

Cross-Sectional Area Reduction Rate (%)

Tensile Strength Reduction Rate (%)

- 7 \( \square \) 19 Strand Rope
- C.F.R.C. Suspender Rope
Impregnating paints for prevention of concrete-structure deterioration

Background

Resin-base paints needs to be repainted periodically at intervals of about a dozen years due to deterioration of organic binder material caused by ultraviolet rays.

Strategy

Impregnating paints which are mostly made from inorganic materials and hardly deteriorate under UV rays, are tested on-site.
Development of painting robots

Painting robot for box girder

Painting robot for tower
4. Socio-Economic Effect of the Project
Time Reduction

**East Route (Kobe-Tokushima)**
- Ferry: 270 min
- Highway: 100 min

**Central Route (Kurashiki-Sakaide)**
- Ferry: 120 min
- Highway: 40 min

**West Route (Onomichi-Imabari)**
- Ferry: 160 min
- Highway: 80 min
Comparison Ferry Fare and Toll

Transportation cost downed by opening HSBE

Compare Ferry / Toll fare

- Akashi ~ Iwaya: 3,780 yen (Ferry before) vs. 2,300 yen (HSBE)
- Tarumi ~ Awaji: 4,370 yen (Ferry before) vs. 3,500 yen (HSBE)
- Uno ~ Takamatsu: 8,040 yen (Ferry before) vs. 4,700 yen (HSBE)
- Kojima ~ Sakaide: 3,500 yen (Ferry before) vs. 4,700 yen (HSBE)
- Mihara ~ Imabari: 2,300 yen (Ferry before) vs. 4,700 yen (HSBE)
- Onomichi ~ Imabari: 4,700 yen (Ferry before) vs. 8,040 yen (HSBE)

1) Ferry fare is price before open, HSBE new fare from 02 July.
2) Ordinary vehicle is 4~5m long.
3) Ferry fare includes one co-driver’s fare.
Passenger increase between Shikoku and Honshu

Passenger between Shikoku and Honshu exceeded 50 million. In comparison with '84, '02 became 1.7 times.
Cargo distribution

Cargo distribution on Br. increased more than Nation Ave (1.29)

Cargo Vol. to Shikoku from nationwide (Truck)

<table>
<thead>
<tr>
<th>Year</th>
<th>Cargo Vol. (10 thousand ton)</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>'87</td>
<td>2,528</td>
<td>1.68</td>
</tr>
<tr>
<td>'02</td>
<td>4,240</td>
<td></td>
</tr>
</tbody>
</table>

Cargo Vol. to Shikoku from Hanshin area and Sanyo area (Truck)

<table>
<thead>
<tr>
<th>Year</th>
<th>Cargo Vol. (10 thousand ton)</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>'87</td>
<td>1,374</td>
<td>1.49</td>
</tr>
<tr>
<td>'02</td>
<td>2,050</td>
<td></td>
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</tbody>
</table>
Traffic Volume

(Vehicles/day)


- Ferry
- East Route
- Central Route
- West Route

West Route open
Akashi Kaikyo Bridge open
Central Route open
Ohnaruto Bridge open
Traffic Volume on Br. Increase 5.3%/y (1988→1997)

Change of traffic on HSBE
(Cross Pref. Boundary, Onaruto+Central Rt.+Tatara Br.)

Year Ave. (Veh./day)

<table>
<thead>
<tr>
<th>Year</th>
<th>Tatara</th>
<th>Central</th>
<th>Onaruto</th>
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<tbody>
<tr>
<td>'88</td>
<td>18,395</td>
<td>25,486</td>
<td>51,880</td>
</tr>
<tr>
<td>'89</td>
<td>16,868</td>
<td>25,486</td>
<td>52,354</td>
</tr>
<tr>
<td>'90</td>
<td>18,395</td>
<td>25,486</td>
<td>52,340</td>
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<tr>
<td>'91</td>
<td>18,395</td>
<td>25,486</td>
<td>52,340</td>
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<tr>
<td>'92</td>
<td>18,395</td>
<td>25,486</td>
<td>52,340</td>
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<tr>
<td>'93</td>
<td>18,395</td>
<td>25,486</td>
<td>52,340</td>
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<tr>
<td>'96</td>
<td>18,395</td>
<td>25,486</td>
<td>52,340</td>
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<tr>
<td>'97</td>
<td>25,486</td>
<td>32,320</td>
<td>67,806</td>
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<td>'98</td>
<td>32,320</td>
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</tr>
<tr>
<td>'03</td>
<td>36,264</td>
<td>36,264</td>
<td>72,528</td>
</tr>
</tbody>
</table>

(FsYear)
Regular Route Bus Number and Passenger on Akashi Br.

- **1998**: 4,063 thousand
- **1999**: 4,443 thousand
- **2000**: 5,924 thousand
- **2001**: 5,589 thousand
- **2002**: 6,300 thousand
- **2003**: 6,795 thousand
- **2004**: 8,725 thousand

**Passenger**

- **1998**: 512
- **1999**: 525
- **2000**: 601
- **2001**: 665
- **2002**: 777
- **2003**: 872
- **2004**: 880

**Bus No.**

- **1998**: 900
- **1999**: 700
- **2000**: 600
- **2001**: 500
- **2002**: 400
- **2003**: 300
- **2004**: 200

(Fiscal y)
Sustainable increase business user like truck and van

Change of Traffic volume by trip objective on Central Rt.

- Total
- Business

Traffic Vol. (Vehicle/day)

- 7.5% / year
- 10% / year

45% (Fs Year)
Enlarging life territory caused by close feeling of islanders

Students in Hakata and Oshima islands enrolment to high school in Imabari city

Ref) National census
*) Islander ratio excluded dormitory students
Tourist to Shikoku Increased by HSBE opening.
In comparison with '87, '03 increased 1.4 times.

Change of Tourist to Shikoku

Ref) Tokushima Ehime Kagawa Kochi Prefecture
Rate of Growth
Gross Regional Product


<table>
<thead>
<tr>
<th>Year</th>
<th>Nationwide</th>
<th>Shikoku</th>
</tr>
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<tbody>
<tr>
<td>1980</td>
<td>9%</td>
<td>4%</td>
</tr>
<tr>
<td>1985</td>
<td>4%</td>
<td>9%</td>
</tr>
<tr>
<td>1990</td>
<td>-1%</td>
<td>-6%</td>
</tr>
<tr>
<td>1995</td>
<td>-11%</td>
<td>-6%</td>
</tr>
</tbody>
</table>

- Ohnaruto Bridge open
- Central Route open
- Akashi Bridge open
- West Route open
Evaluation of Effectiveness

Bridge user Benefit and Cost Benefit Ratio

Direct benefit 250 Billion yen 2 Billion $ (in 2000) / year
40 years after open traffic total benefit 8.7 Trillion yen
$B/C = 1.7$

40 years Total benefit

(B) Benefit

8.7 Trillion yen

(C) Cost

Construction and maintenance cost in 40 years
5.2 Trillion yen

Cost benefit Ratio

$B/C = 1.7$

B and C calculated by depreciation ratio 4% in 2000

Direct benefit means bridge users’ total effectiveness of cost cut of running expense and time saving.
5. Appendix
Construction Cost

Kobe- Naruto Route
90km  1,470 billion Yens
     13.3 billion Dollars

Kojima- Sakaidi Route
40km  1,170 billion Yens
     (HIGHWAY 670 billion)
     (RAILWAY 500 billion)

Onomichi- Imabari Route
60km  750 billion Yens

Total
190km  3,390 billion Yens
       30.8 billion Dollars
Future Strait Crossing Projects

- Tokyo Bay Crossing
- Ise Bay Crossing
- Kitan-Kaikyo Crossing
- Hoyo-Kaikyo Crossing
- Kanmon Crossing
- Amakusa-Shimabara-Nagashima Crossing
Change of Construction Investment

![Graph showing the change of construction investment over fiscal years from 1985 to 2005. The graph compares total investment, non-government investment, and government investment. The x-axis represents fiscal years from 1985 to 2005, and the y-axis represents investment in trillion Yen. The graph shows a distinct trend for each category, with total investment peaking in the mid-1990s, non-government investment increasing steadily until the late 1990s, and government investment decreasing throughout the period.]
I appreciate your kind cooperation.