CHALLENGES OF AN ICONIC PEDESTRIAN BRIDGE

N. Anwar, T.H. Aung
P. Norachan
AIT Consulting, Asian Institute of Technology
INTRODUCTION
Location and Iconic Nature
The Layout - Connects a New Hotel to Airport
Introduction

• What makes it iconic?
  – Envisaged as a symbol for area and Airport

• What makes it a different from other helical bridges?
  – One of famous ones is the Double Helix in Singapore
Key Challenges

- Architect pre-decided the form and proportion and no compromise possible
- Flatness of the Helix presented major challenge
- Large loading from pedestrian traveler
- Large loading from cladding
- Larger span
- No continuity
- High vertical Seismic force
Overall View

60 m long
Elliptical section, made up of helical form

Depth = 8 m
Width = 21 m at entrance and 24 m at mid-span
Effect of Section Aspect Ratio

Most other Helical Bridges

Current Bridge Form
Key Issues

• Large stresses in helix pipes due to bending

• No adequate shear transfer

• Large deflections

• Large vibrations

• In-adequate support force transfer
Comparison with Singapore Helix
The Solution to Challenges

SELECTION OF STRUCTURAL SYSTEM
Structural Systems

• Studied various structural systems

  1) Single helical ring

  2) Single helical ring with truss

  3) Double helical ring
Option 1 – Single Helix

Top chord

Bottom chord (I-section girders)

Single helical ring
Option-2: Single Helix + Truss

- Single helical ring
- Top chord
- Bottom chord (I-section girders)
- Truss
Option-3: Double Helix
Helical Rings

• Primary Ring
  – Use pipe section 400 mm dia.
  – Thickness varied 5 mm to 22 mm

• Secondary Ring
  – Use pipe section 400 mm dia.
  – Thickness varied 6 mm to 12 mm
Comparison of Systems

W₁ = 23,7 m
W₂ = 16,6 m
H = 7,8 m

W₁ / H = 23,7 / 7,8 = 3,04
W₂ / H = 16,6 / 7,8 = 2,13
Conclusions

• Helical bridges should preferably have circular section form

• For present project, a compromise structural system was developed, using double helical rings, keeping external form, and providing structural skeleton
INTRODUCTION

• Structural System
  – Steel bridge with concrete deck
  – Resting on concrete piers
    • Piers have different heights, 25 m and 20 m
  – Pile foundation

• Cladding System
  – 4 mm thk. aluminium metal skin attached to steel frame
LOADING CRITERIA

• Self-weight
  – Structural members, cladding, floor finishing, ceiling, fixed service equipment, travelator

• Live Load
  – Pedestrian live load = 4 kPa

• Wind Load
  – Basic wind speed = 250 kph

• Seismic Load
  – PGA = 0.5 g for Design Basis Earthquake

• Thermal Load
  – Temperature changes = 25°C
UBC-97 response spectrum was used, in which PGA was scaled to 0.5 g.
FINITE ELEMENT MODELING
Finite Element Model

- 3D model considering detailed structural skeleton
  - Piers (Frame element)
  - Steel helical rings (Frame element)
  - Steel girders (Shell element)
  - Concrete deck (Shell element)
  - Mechanical pot bearings (Linear link element)
  - Pile cap (Shell element)
  - Piles (Frame element)
  - Lateral springs along pile shaft
Single Helical Ring System

• Members
  – Pipe sections in helical rings and top chord
  – Built-up I-sections in bottom chord
• Stiffness was not sufficient to control the deflection for serviceability requirements.
• Due to flatness of helical rings (aspect ratio between depth and width of the ring)
Single Helical Ring with Truss

- **Members**
  - Pipe sections in helical rings and top chord
  - Built-up I-sections in bottom chord
  - Two trusses were added.
- **Stiffness was improved to control the deflection.**
- **However, truss conflicted with architectural requirements.**
Double Helical Ring System

- **Primary ring (Inner)**
  - Main structural system
- **Secondary ring (Outer)**
  - Support the cladding
- **Members**
  - Pipe sections in helical rings and top chord
  - Built-up I-sections in bottom chord.
- **Both serviceability and architectural requirements are satisfied.**
Reduction in Flatness of Helical Ring

\[ W_1 = 23,7 \text{ m} \]
\[ W_2 = 16,6 \text{ m} \]
\[ H = 7,8 \text{ m} \]
\[ \frac{W_1}{H} = \frac{23,7}{7,8} = 3,04 \]
\[ \frac{W_2}{H} = \frac{16,6}{7,8} = 2,13 \]
ANALYSIS RESULTS
Modal Analysis

Mode 1 = 1.29 sec

Mode 2 = 1.03 sec

Mode 3 = 0.78 sec

Mode 4 = 0.72 sec
(Vibration mode of bridge only)
Gravity Load Analysis

- Cladding weight contributed a significant portion of weight and mass of the bridge.

- Vertical Deflection
  - Dead load = 152 mm
  - Live load = 52 mm

Note: Exclude weight of pier and foundation
Axial Force Diagram

Top chord and helical rings under gravity loading
(Maximum compressive force in top chord at mid span = 3600 kN)
Flexural Stresses

Built-up I sections under gravity loading (Unit: MPa)
Lateral Load Analysis

• Seismic Loading
  – Response spectrum analysis
  – Both horizontal and vertical ground shakings were considered.
  – Approximately 30% of horizontal ground shaking was considered as vertical ground shaking.
  – Response modification coefficient, $R = 1.5$

• Wind Loading
  – Linear static analysis
Base Shear

**Design Base Shear above Ground Level**

<table>
<thead>
<tr>
<th>Direction</th>
<th>Seismic (kN)</th>
<th>Wind (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal</td>
<td>7,200</td>
<td>350</td>
</tr>
<tr>
<td>Transverse</td>
<td>5,500</td>
<td>950</td>
</tr>
</tbody>
</table>

**Design Base Shear Percentage above Ground Level**

<table>
<thead>
<tr>
<th>Direction</th>
<th>Seismic (%)</th>
<th>Wind (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal</td>
<td>35.8</td>
<td>1.7</td>
</tr>
<tr>
<td>Transverse</td>
<td>27.3</td>
<td>4.7</td>
</tr>
</tbody>
</table>
DETAILED DESIGN
Detailed Design

• Structural steel design
  – ANSI/AISC 360-05

• Reinforced concrete
  – ACI 318-05

• Carried out value engineering to achieve cost-effectiveness design
Helical Rings

• Primary Ring
  – Use pipe section 400 mm dia.
  – Thickness varied 5 mm to 22 mm

• Secondary Ring
  – Use pipe section 400 mm dia.
  – Thickness varied 6 mm to 12 mm

Large bending stress regions (10-12 mm thk.)
Top and Bottom Chords

• Top Chord
  – Use pipe section 500 mm and 600 mm dia.
  – Thickness varied 8 mm to 16 mm
  – Primarily designed for compression forces

• Bottom Chord
  – Built-up I-sections
  – Depth varied based on profile of the primary ring
Steel Frame

• Two steel frames were added at each pier support.
• Transfer the axial forces from the inclined helical rings to the support.
• Reduce relative deflection between top and bottom chords.
• Use pipe sections of 550-600 mm diameter with the thicknesses of 16 mm and 20 mm
Effect of Steel Frames

Without Steel Frame

Deflection = 128 mm
Deflection = 19 mm

With Steel Frame

Deflection = 28 mm
Deflection = 19 mm
Piers

- Considered slenderness effect
- Magnified the moments for second order effects.
- Moment demand increased about 5-10% for sway and non-sway conditions.
Construction Sequence

**Stage 1:** Bridge segments adjacent to the support are fabricated with 10 m overhang from the edge of shoring supports to avoid disruption of traffic under the bridge.
Construction Sequence

**Stage 2:** Temporary tension hangers are provided in preparation for fabrication and placement of middle segment.

Provide camber for the deflection under 100% of dead load plus 25% of live load which is about 165 mm at the mid-span.
Thank you.