TECHNICAL SESSION 4

Post-Tensioned & Cable Stayed Bridges

Moderator

John Crigler
VSL
Hanover, MC
Provencher Bridge:
Concrete Tower with steel skin
Top of tower 69 m above deck
Tower surface zinc metallized
Plaza supported on post-tensioned spline beams and cables
Three types of cables:
- 2 Pylon Balance cables
- 6 Plaza cables
- 36 Bridge cables

Cables sizes varied from 9 to 19-0.6 strands
Strands were waxed and PE sheathed
Plaza will accommodate a glass enclosed restaurant

Plaza and Pylon Balance cables

Having dinner next to a cable anchorage!
Plaza and Pylon Balance cables
Back Stay cables installed
Second pair of back span cables

Tower shaft is hollow concrete section with outer steel shell and pinnacle
Cables are anchored by clevis-pin connector plate

Tower Cable Anchorages:
Steel plate transmits the forces between opposite cables
Pin connection seems to provide high friction damping

Cable Anchorage at the Pylon- Clevis Type
Shown with non-replaceable strands

Clevis type cable anchorage:
fatigue and static strength test
Heavy wall pipe and welded pin plates
Wedge plate threaded into clevis pipe

2 million cycles 160 MPa stress range
**Cable Anchorage at the Deck - Standard DYNA-Grip System**
- PE pipe co-extruded white color
- External Helix to suppress rain-wind oscillations

**Original Construction Method: Precast deck segments**

**Original Precast Construction Cycle (10 m deck length):**
- Two 3.75 meter typical segments plus one 2.5 m diaphragm segment
- Erection frame supported by a temporary cable

**Original Design: Deck layout and cross-section**
- * Diaphragm extends beyond box section to support cables
- * Interior webs

**Provencher Bridge, Winnipeg**
- Completed October 2003

**Redesign Features**
- Cast-in-place segmental
- Back span on false-work
- Main span: cantilever method
- Five day construction cycle
- Cable PE pipe with external helix
- Lightweight and mobile form-traveler
- Eliminate temporary cables
Cast-in-Place Box Girder:
* Eliminate internal webs
* Adjust dimensions to match weight and stiffness of original section
* Typical cantilever segment: 10 meters
* Five day construction cycle

Precast Cable Anchorage Blocks:
* Roughened interface joint
* High strength and quality concrete
* Shear friction design approach

Construction Equipment is the key to successful segmental bridges!

Provencher Bridge - Form Traveler

Complex 3D Computer Model
- Many load cases & boundary conditions
- Very light truss structures with easy adjustment and advance

Copyright - Post-Tensioning Institute 2004 PTI Technical Conference Session 4 Khaled Shawwaf - Provencher Bridge Cables

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First Cable- steep slope
Precast cable anchorage block- Fix in position and orientation
Temporary floating support for cable extension- Transmit cable force to FT

Last Cable- Flat slope
Position of floating cable anchorage moves to front of FT
No bracing for the top chords of the trusses

Rear Reaction Support
Shown with roller during advancing

Design
Supply
Assemble
Erect
Operate
Form Traveler

Design load transfer of precast cable block
3D geometry control for installation
Eliminate bolted cable extension pipe

Geometry Control of Cable Anchorage Precast Block
Five day construction cycle
Fast and accurate procedure to set the location of the cable precast block
Precast block 'Caddy'

Precast Block 'caddy'
Adjustments in longitudinal and vertical directions
Rotation of precast block until it rests on bracket
Bracket position is the same for all cables

During concreting the wedges at the permanent cable anchor are retracted
The cable strands are securely anchored with clamped wedges at the front of the floating cable anchorage
Cable force transferred to the permanent anchorage after deck has reached required strength and post-tensioned

Floating cable anchorages to support Form-Traveler
Location and angle vary for each cable
Transfer cable loads to bridge by releasing force in Dywidag bars

Cable Forces and Reactions on the Form Traveler
Reaction Brackets against diaphragm to resist Longitudinal force of cable

Cable Reaction bracket and Precast Block bracket must be removed before advancing the form traveler

Removed Precast Block to allow advance of FT

Advancing the FT: Launching beam supported by outrigger brackets
Hillman rollers on top of launching beam- Lateral guides

Outrigger beams stressed down to deck
Start of FT launching- 1 meter advancing jacks

Launching beam supported by four outrigger brackets cantilevering beyond the sides of the deck

Are small bridges more trouble than large structures?

Form Traveler Advancing:

FT is at the end of advancing cycle- Preparing to cast next segment

Reaction Bracket to resist longitudinal cable component- Most critical member
End of FT Launching
Very tight clearances!
Advance in one hour!

At rear of FT the uplift reaction is resisted against the bridge soffit
Jacks allow the elevation adjustment of the front
Hillman rollers for advancing and guiding the FT

Outer side forms of box girder - Removed before advancing FT

Side forms in place to cast next segment - Precast block fixed in place

Top Slab Reinforcement and Post-Tensioning Tendons
36 mm Dywidag bars stressed at every segment and extended into next

Provencher Bridge
Cable Fabrication & Installation
Critical path activity
Tower Clevis Anchorage:
Strands were cut to length laid out and arranged in a parallel pattern

Threaded anchor head was placed and the wedges securely seated

Clevis was then prepared for installation over anchor head

Note hand hole for strand exchange

Clevis anchor assembly was screwed on the threaded anchor head

Cable is now ready for lifting and installation

The clevis anchorage is fixed to the lower plates with 120 mm pins

Cable with large sag

Ready for pulling into the deck anchorage
Cable is being pulled into deck anchorage

Anchored at tower only

Fully stressed cable

Develop new Clevis cable anchorage

Vacuum injection of anchorages with Dyna-Shield anti corrosion filler

Tower Post-Tensioning:

12 and 19-0.6 tendons

Dead anchors at the bottom in a block-out or buried in the shaft section

Stressing anchors at different lifts

Treat tendons as ‘Rock Anchors’:

Cast duct in each lift

Cast tendon anchorage in upper lift

Pre-assemble tendons

Place spacers between strands in Bond Length

Insert tendon into duct cavity

Grout the Bond Length

Stress tendon and grout remainder of tendon

Dead end anchored by BOND

Cable stay pipe with external helix suppressed all rain-wind vibrations
**Provencher Bridge**

**Cable Stressing**
Deviation of individual strand forces within each cable

How much force deviation may be allowed between the strands within a cable?

**Provencher Pedestrian Cable Stayed Bridge**

**Cable Designation:** CW18

**Cable Length Allowable Tolerance:**
- ±5 mm for L=25 meters
- ±10 mm for L=125 meters

**CABLE LENGTH = 107m**

<table>
<thead>
<tr>
<th>Strand</th>
<th>Force</th>
<th>Off from Ave</th>
<th>Diff, kN</th>
<th>Force</th>
<th>Off from Ave</th>
<th>Diff, kN</th>
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<tbody>
<tr>
<td>1</td>
<td>98.1</td>
<td>-0.3%</td>
<td>-0.3</td>
<td>99.4</td>
<td>-0.7%</td>
<td>-0.7</td>
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<tr>
<td>2</td>
<td>96.3</td>
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<td>-0.1</td>
<td>96.1</td>
<td>-1.1%</td>
<td>-1.0</td>
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<tr>
<td>3</td>
<td>94.3</td>
<td>-2.1%</td>
<td>-2.0</td>
<td>98.7</td>
<td>-1.7%</td>
<td>-1.6</td>
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<tr>
<td>4</td>
<td>97.5</td>
<td>1.2%</td>
<td>1.2</td>
<td>97.5</td>
<td>0.4%</td>
<td>0.4</td>
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<tr>
<td>5</td>
<td>97.9</td>
<td>1.6%</td>
<td>1.5</td>
<td>97.9</td>
<td>0.8%</td>
<td>0.7</td>
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<tr>
<td>6</td>
<td>98.2</td>
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<td>-1.2</td>
<td>98.6</td>
<td>2.8%</td>
<td>2.5</td>
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<tr>
<td>7</td>
<td>95.7</td>
<td>-0.6%</td>
<td>-0.6</td>
<td>97.5</td>
<td>0.4%</td>
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<tr>
<td>8</td>
<td>97.9</td>
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<td>-0.9</td>
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<td>9</td>
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<td>98.6</td>
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<td>10</td>
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<td>-1.2</td>
<td>96.1</td>
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<tr>
<td>12</td>
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<td>-1.7</td>
<td>97.5</td>
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<td>0.4</td>
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<td>13</td>
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<td>-0.6</td>
<td>96.1</td>
<td>-1.1%</td>
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<td>14</td>
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<td>-0.3%</td>
<td>-0.3</td>
<td>96.1</td>
<td>-1.1%</td>
<td>-1.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1340</strong></td>
<td></td>
<td></td>
<td><strong>Total</strong></td>
<td><strong>1360</strong></td>
<td></td>
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<tr>
<td><strong>Average</strong></td>
<td><strong>96.3</strong></td>
<td><strong>Range</strong></td>
<td><strong>3.9</strong></td>
<td><strong>Range</strong></td>
<td><strong>3.6</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Computed Range</strong></td>
<td><strong>7.8</strong></td>
<td></td>
<td></td>
<td><strong>7.6</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Force Deviation due to Allowable Length Tolerance (±5 mm), kN**

**Force Deviation due to Allowable Length Tolerance ± 1.25% Force**
Strand forces in 9N & 9S cables were not the same due to plaza!

<table>
<thead>
<tr>
<th>Strand</th>
<th>CW9N Diff, kN</th>
<th>CW9S Diff, kN</th>
<th>Average Diff, kN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.8%</td>
<td>0.8%</td>
<td>1.4%</td>
</tr>
<tr>
<td>2</td>
<td>0.4%</td>
<td>0.8%</td>
<td>0.5%</td>
</tr>
<tr>
<td>3</td>
<td>-4.4%</td>
<td>2.4%</td>
<td>0.0%</td>
</tr>
<tr>
<td>4</td>
<td>2.8%</td>
<td>-5.5%</td>
<td>-1.8%</td>
</tr>
<tr>
<td>5</td>
<td>1.6%</td>
<td>2.4%</td>
<td>1.1%</td>
</tr>
<tr>
<td>6</td>
<td>1.1%</td>
<td>-0.9%</td>
<td>0.1%</td>
</tr>
<tr>
<td>7</td>
<td>-0.3%</td>
<td>0.8%</td>
<td>0.5%</td>
</tr>
<tr>
<td>8</td>
<td>-0.3%</td>
<td>0.0%</td>
<td>0.1%</td>
</tr>
<tr>
<td>9</td>
<td>0.4%</td>
<td>1.1%</td>
<td>0.3%</td>
</tr>
<tr>
<td>10</td>
<td>-4.4%</td>
<td>-1.6%</td>
<td>-3.0%</td>
</tr>
<tr>
<td>Tot F</td>
<td>1176</td>
<td>917</td>
<td>1176</td>
</tr>
</tbody>
</table>

Computed Range: ±2.5% MUTS = ±6.5 kN

Cable 9: Individual strand forces, kn

L = 37 meters

Provencher Pedestrian Bridge
A new feature in the Winnipeg skyline
A bridge between the French Ville and Downtown

Provencher Bridge, Canada
Owner: City of Winnipeg
Engineer: Wardrop Ltd.
Contractor: M.D. Steele, Ltd.
CIP Proposal: DSI
Post-Tensioning: DSI
Cables: DSI
Form-Traveler: DSI
Const. Engin.: Buckland-Taylor
Stay Cable Enhancements

John Crigler & Hans Ganz

Stay Cable Enhancements

- PTI Recommendations
- 100 Design Year Life
- Monostrand Stressing
- Vibration Control
- Monitoring

4.1 Corrosion Protection

- Performance
- 2 Nested Barriers
- Free Length
- Anchorage Length

4.1.2 Corrosion Protection

- 2 Nested Barriers
- Internal Barrier - Full Length
- External Barrier - Free Length

4.1.2.1 Barriers

- Anchorage - Free Length Interface
- Performance

4.1 Corrosion Protection

4.1.1 General

This specification covers only stay cable systems that use prestressing wire, strand or bar for the main tension elements. As a result, the corrosion protection systems are limited to those that are used specifically for the prestressed wire, strand or bar.

Stay cables shall be provided with a corrosion protection system capable of preventing the MTE from corrosion by the design life of the cables. A minimum of two nested, qualified barriers shall be provided for MTE corrosion protection. Requirements for the corrosion protection system shall be in accordance with the free length and the anchorage length.
Climate

Kemijoki Bridge, Finland

Wadi Leban Bridge, Saudi Arabia

Batam Tonton Bridge, Indonesia

Internal Barrier - Tightly Extruded Monostrand:

Standard

Galvanized

Strand Qualification Test - Static leak tightness test of strand (1m water head)

External Barrier - HDPE Stay Pipe

Black

Co-Extruded

HDPE Stay Pipe

Accelerated Ageing Tests in Weatherometer (7 months)

Colored Stay Pipe Samples

Weatherometer

Tensile and Bending Tests
HDPE Stay Pipe Colorimetric Tests

Stay Cable Anchorages

Guide Deviator

Stay Cable Design Life

Design Life Example

<table>
<thead>
<tr>
<th>Aggressiveness of the environment : C5 (ISO 12944-2) (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design life of the stay cable system</td>
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<tr>
<td>--------------------------------------</td>
</tr>
<tr>
<td>Replaceable</td>
</tr>
<tr>
<td>Not replaceable</td>
</tr>
<tr>
<td>Not replaceable</td>
</tr>
<tr>
<td>Replaceable</td>
</tr>
</tbody>
</table>

(1) Only indicative (to be specified by the Engineer)
(2) Only indicative (to be defined by the stay cable system supplier)
## Design Life Example

<table>
<thead>
<tr>
<th>Aggressiveness of the environment</th>
<th>Design Life of the Stay Cable System</th>
<th>Design Life of the Stay Cable System</th>
<th>Period between Subsequent Maintenance Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replaceable</td>
<td>25 years (2)</td>
<td>25 years (2)</td>
<td>25 years (2)</td>
</tr>
<tr>
<td>Not Replaceable and Easy Access</td>
<td>100 years (3)</td>
<td>25 years (2)</td>
<td>15 years (3)</td>
</tr>
<tr>
<td>Not Replaceable and No Access</td>
<td>108 years (5)</td>
<td>No maintenance</td>
<td>No maintenance</td>
</tr>
</tbody>
</table>

(1) Only indicative to be specified by the Engineer. (2) Only indicative to be defined by the stay cable system supplier.

## Monostrand Stressing

- Initial Stressing to Force
- Subsequent Stressing to Elongation
- Automatic Lift-Off
- Electronic Record

## Strand by Strand Installation

## Automatic Monostrand Stressing
Factors That Influence Stay Installation Forces

Cable Sag

Deck Deflection

Pylon Deflection

BASIC THEORY

Equal Load in All Strands

Strand Software

Cable Force Checking

Controlling Vibrations
**Friction Damper Performance**

Tongji University Test February 2004

First Mode

-200
-150
-100
-50
0
50
100
150
200

Anchor Ch2 Ch3 Anchor

Second Mode

-100
-80
-60
-40
-20
0
20
40
60
80

Anchor Ch2 Ch3 Anchor

Third Mode

-80
-60
-40
-20
0
20
40
60
80

Anchor Ch2 Ch3 Anchor

1st Mode Test 2

-100
-80
-60
-40
-20
0
20
40
60
80
100

178355532709 886 10631240141715941771 1948 212523022479 26562833301031873364

Displacement CH002

Mode 2 Test 1

-100
-80
-60
-40
-20
0
20
40
60
80
100

164327490 653 816 979 11421305 1468 163117941957 2120 2283 2446 26092772 2935 3098

Displacement CH002

Mode 3 Test 2

-80
-60
-40
-20
0
20
40
60
80
100

206 411 616 821 1026 1231 1436 1641 1846 2051 2256 24612666 2871 3076 3281 3486 3691 3896

Displacement CH002

Maximum damping measured > 7% @ Ld = 0.023 L

60 Seconds

**Monitoring**

**Remote Monitoring**

**Load Cells**

- Multistrand Split-Load Cell
- Single Strand Load Cell

**Detailed Vibration Assessment**
In 1979, there were a total of TWO bridges across the Yangtze River:
- Wuhan
- Nanjing

Now, there are more than FORTY!

Up to 1978, there were only THREE large bridges in all of China

1st Yangtzu River Bridge, Nanjing
In the City of Chongqing, the first major bridge was built in 1980.

Today, there are 26 major bridges (among a total of 4,300):
- 5 Suspension
- 8 Cable-stayed
- 3 Arched
- 7 Concrete Girder
- 3 Steel Trusses

Nanpu Bridge, Shanghai
- The first major long span bridge in China.
- 423-meter span
- Completed in 1991

Yangpu Bridge
- 602-meter span
- Completed in 1994

Nanpu Bridge
- Completed in 1991

Xupu Bridge
- 590-meter span
- Completed in 1997
Wuhan Bridge
- 400-meter span
- Completed in 1995

Tungling Bridge
- 432-meter span
- Completed in 1995

Hedong Bridge
- 360-meter span
- Completed in 1998

Dongting Lake Bridge at Yueyang
- Two 310 meter spans
- Completed in 2001

Nanjing Second Yangtze River Bridge
- 628-meter span
- Completed in 2001
Nanjing Third Yangtze River Bridge
- 648-meter span
- Under construction

Sutong Yangtze River Bridge
- 1088-meter span
- Under construction

Cable-stayed Bridges

Hangzhou Bay Bridge: 36 km long across the Hangzhou Bay

Humen Bridge
- 270-meter span
- Completed in 1997

Northern Approach, Nanjing 2nd Yangtze Bridge
- 165-meter span
- Completed in 2002
Chongqing, China: December 28, 2003
A historic moment!

• Groundbreaking for two world record span bridges on the same day, in the same city.

• And, designed by the same US consultant
Caiyuanba Bridge

Shibanpe Bridge Site

The advantages of both steel & concrete combined to create a world record span.

Chongqing Shibanpe Bridge

- 330-meter span

Qingchuan Bridge

- 280-meter span
- Completed in 2000

Changfeng Bridge

- 240-meter span
- Completed in 2001
Meixihe River Bridge
- 288-meter span
- Completed in 2000

Wanxian Yangtze River Bridge
- 420 meter span
- Completed in 1997

Yajisha Bridge
- 360-meter span
- Completed in 2000

Yajisha Bridge

Lupu Bridge
- 550-meter span
- Completed in 2003

A sampling of our current projects...
Dagu Bridge, Tianjin, China

Dagu Bridge

Dagu Bridge

Dagu Bridge

Dagu Bridge