Recent Innovations in Cable-Stayed Bridge Design and Construction

Presented by
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Introduction
Brief history of cable stayed bridges
Modern cable stayed bridge structural analysis
Current practice of stay cable installation
Elements of modern stay cables
Presentation review and conclusion
Cable Stayed Bridge History

- Cable stayed bridge is a 400 year old concept
- Modern cable stayed bridges started in 1950’s in Europe
- Pasco-Kennewick Bridge first modern cable stayed bridge construction in the United States in late 1970’s
Cable Stayed Bridge History

- Parallel Bar Cable Stays (PBC)
- Parallel Strand Cable Stays (PSC)
- Parallel Wire Cable Stays (PWC)
- Multi-Layer Cable Stays (MLS)
Cable-Stayed Bridge History

- Modern cable stayed bridges
  - Parallel Strand Stay Cables (PSC)
  - Multi-Layer Cable Stays (MLS)
Modern Structural Analysis

- Evaluate the geometry of the bridge around other project needs
  - Roadway geometry
  - Vertical restrictions
  - Undercrossing restrictions
Modern Structural Analysis

- Define the geometry of the main bridge elements
  - Deck width
  - Main span length
  - Side span length(s)
Modern Structural Analysis

- Define the geometry of the main bridge elements
  - Superstructure type and geometry
  - Substructure type and geometry
  - Cable types and arrangement
Define how the main bridge elements will be constructed

- Balanced Cantilever
- Unidirectional Cantilever
- Cast-in-Place or Precast
- Temporary Supports
Modern Structural Analysis

- Develop initial global analysis model
  - Low discretization
  - Evaluate probability of successfully designing main elements
Modern Structural Analysis

- Develop global analysis and design model
- Advance bridge geometry to wind load analysis and testing to obtain design data
- Advance bridge geometry to obtain geotechnical and seismic design data
Modern Structural Analysis

- Develop local analysis and design models
- Integrate design data from wind, geotechnical and seismic analysis
- Iterate as necessary to produce a successful design
Modern Structural Analysis

- Common Design and Analysis Software
  - Global Models
    - LARSA 4D
    - RM Bridge
    - MIDAS Civil
  - Local Models
    - ADINA
    - ABACUS
Current Practice of Cable Installation

- Step 1: Survey bridge geometry
- Step 2: Move stay cable construction equipment into position
Current Practice of Cable Installation

- Step 3: Weld HDPE stay pipe to required length
- Step 4: Mark and cut king strand
- Step 5: Pass king strand through stay pipe and secure
Current Practice of Cable Installation

- Step 6: Lift stay cable to upper anchor location and secure stay pipe to tower leg
- Step 7: Pull stay cable to lower anchor location
Current Practice of Cable Installation

- **Step 8:** Pull king strand through live end anchor head, accurately position the mark from the face of the anchor head
- **Step 9:** Install monostrand jack on live end of king strand
- **Step 10:** Pull king strand through dead anchor head and hand seat wedge
- **Step 11:** Stress king strand to required force
Current Practice of Cable Installation

- **Step 12:** With king strand now supporting stay pipe, run winch wire and sled down through stay pipe
- **Step 13:** Cut and strip live end of next strand, connect to sled and pull strand up stay pipe
- **Step 14:** Run next strand through live end anchor, install wedge and monostrand jack
Current Practice of Cable Installation

- **Step 15:** Pull next strand through dead anchor head and hand seat wedge
- **Step 16:** Stress next strand to required force
- **Step 17:** Repeat steps 13 thru 16 till all stay cable strands are installed
Current Practice of Cable Installation

- **Step 18:** Apply corrosion inhibitor to temporarily protect strands at anchorages
- **Step 19:** Repeat Steps 1 thru 18 for all remaining stay cables
Current Practice of Cable Installation

- Step 20: Make final adjustments to cable lengths
- Step 21: Lower expansion sleeves
- Step 22: Install tension ring and friction damper
- Step 23: Cut strand tails, install anchor caps and inject epoxy into anchor caps
Strands and Monostrand Stressing

- Modern stay cable strand
  - 0.62 inch diameter seven wire strand
  - 7% more area than 0.60 inch diameter strand
  - 15 strands 0.62 dia. = 16 strands 0.60 dia.
Strands and Monostrand Stressing

- Modern 0.62 diameter stay cable strand
  - 3% more dia. than 0.60 inch diameter strand
  - Still works with all 0.60 hardware and accessories
Strands and Monostrand Stressing

- Modern stay cable strand
  - Grade 270, ASTM A416 for Greased and Sheathed
  - Grade 270, ASTM A882 for Epoxy Coated
  - CFCC (Carbon Fiber Composite Cable)
Strands and Monostrand Stressing

- Stress all stay cable strands at once (previous practice)
- Monostrand stressing stresses each stay cable strand individually (current practice)
Strands and Monostrand Stressing

- The goal of monostrand stressing should be to have all strands in the stay equal to each other and totaling to the global stay force by stressing each strand individually.
Strands and Monostrand Stressing

- Initial Stressing Considerations
  - Number of strands to stress
  - Weight of stay pipe
  - Stiffness of entire stay cabled structure
  - Stiffness of each element relative to each other.
Strands and Monostrand Stressing

- First step is to install the first strand (aka the king strand)
- All subsequent strand installed is stressed to match the current king strand force at completion of strand stressing
Strands and Monostrand Stressing

- Single strand stressing is accomplished in two stages
  - Stage 1: Stress stay to percentage of final force to install all strands and control cable sag
  - Stage 2: Retention all strands to final force desired at time of installation
Strands and Monostrand Stressing

- **Stage 1 calculation considerations**
  - Structural stiffness changes with the installation of each subsequent strand in a stay cable
  - A way calculate is to start with all strands assumed to stressed then de-stressing one by one to determine king strand force
Strands and Monostrand Stressing

- Stage 2 calculation considerations
  - Minimal change in stiffness as all strands are already installed
  - Neither ending force or beginning force in strand is zero
Strands and Monostrand Stressing

- Non-zero strand force complicates mathematics for Stage 2
- Once Stage 1 complete, determining the “king strand” force is more difficult as the rest of the strands are slaking during stressing.
Strand and Monostrand Stressing

- A solution is to use an iterative procedure for Stage 2 calculations
  - Assume a king strand force and iterate until an appropriate solution has been reached.
Elements of Modern Stay Cables

- Dead end anchorage
  - Protection cap
  - Steel anchor head
  - Neoprene O-ring
  - Steel bearing plate
Elements of Modern Stay Cables

- Dead end anchorage
  - Individual strand extension tubs and deviator assemblies
  - Steel guide pipe
  - Extension pipe and damper frame
  - Stay pipe HDPE support element
Elements of Modern Stay Cables

- Live end anchorage
  - Protection cap
  - Adjustable steel anchor head
  - Ring nut
  - Steel bearing plate
Elements of Modern Stay Cables

- Live end anchorage
  - Individual strand extension tubs and deviator assemblies
  - Transition pipe with mortar inside steel guide pipe
  - HDPE shim within to connect HDPE stay pipe to guide pipe
Elements of Modern Stay Cables

- Wedges
  - Specific to stay cable strand
  - Three wedge system
  - Typically single use wedges
Elements of Modern Stay Cables

- Tower cradles
  - Steel cradle sheathing
  - Steel cheese plates
  - Individual steel sleeve pipe for strands
Elements of Modern Stay Cables

- Tower cradle installation
  - Sheathing, cheese plate and sleeve pipes pre-fabrication
  - Secure tower cradle before tower concrete lift placement
  - Grout void space between sheathing and sleeve pipes
Elements of Modern Stay Cables

- **Tower Cradle System benefits**
  - Optimizing tower sections - reduces demands on towers by eliminating splitting forces
  - No “pinching” or “bundle” stress on strands that had to be accounted for in traditional saddles
  - Strand by strand replacement now possible (was not possible with traditional saddles)
Elements of Modern Stay Cables

- **Tension Rings**
  - Located inside stay pipe before strands enter steel guide pipes
  - Bundles individual strands together to act as one strand
  - Reduces individual strand and stay cable vibrations
Elements of Modern Stay Cables

- Internal friction dampers
  - Located at the deck level anchorages inside the stay pipe
  - Systems typically supply sufficient damping for most sizes and lengths of stay cables
  - Adjustable to actual field conditions
Elements of Modern Stay Cables

- External Dampers
  - Hydraulic damper systems
  - Piston damper systems
  - Provides higher levels of damping than internal dampers
Elements of Modern Stay Cables

- HDPE stay pipes
  - Helical fillets help reduce dry cable vibration
  - Helical fillets also reduce rain wind induced vibrations (RWIV)
  - HDPE pipe meeting ASTM F714 highly durable and resistant to UV damage
Presentation Review

- Brief history of cable stayed bridges
- Modern cable stayed bridge structural analysis
Presentation Review

- Current practice of stay cable installation
- Elements of modern stay cables
Conclusion

- Modern cable stayed bridges
  - Signature structures
  - Very efficient both structurally and financially (100 to 150 year service life typical)
  - Integrates design, construction and long term maintenance
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QUESTIONS?

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