Effective Inspection and Monitoring of Post-tensioned Structures and a Review of Preventative Maintenance Issues

Dick Feast
Amey Infrastructure Services
Principal Consultant
Professional Services:
Whole Life Asset Management
The Advantages of Using Post-tensioned Structures
The Advantages of Post-tensioned Structures

- Post tensioning techniques have allowed designers and contractors to build bridges and viaducts in what seemed impossible places:-
  - At great heights, over rivers and valleys
  - Elevated roadways over restricted sites
  - Dramatically bridging navigable seaways
The Advantages of Post-tensioned Structures

- A technique that allows long beams lengths to be achieved
- Reduces deflections and allows high/span depth ratios
- Improves durability by the reduction or elimination of cracking
- More efficient utilization of steel and concrete material
Post-tensioned bridges in Hong Kong
Post-tensioned Bridges Hong Kong
Post-tensioned Bridges Hong Kong
Post-tensioned Bridges in Singapore

Construction innovations on Singapore's Sentosa Bridge
Post-tensioned Bridges in USA
The Hong Kong Bridge Stock

The Importance of post-tensioned bridges to Hong Kong:

– The most common structures in Hong Kong are multi-span concrete viaducts
– More than 30% of these structures are post-tensioned
– Most of the large span “landmark” concrete structures are post-tensioned
– Post-tensioned bridges are vitally important elements of the infrastructure of Hong Kong
Disadvantages of Post-tensioned Bridges are:-

- The concentrations of tendons into several large cables make bridges vulnerable to localised corrosion
- The risk of corrosion of tendons depends on the quality and integrity of the cement grout to protect them from the ingress of oxygen, water, chlorides and other deleterious elements
Disadvantages:-

- The consequences of the failure of the principal tensile load-carrying component are usually catastrophic.
- A possible lack of redundancy within the structure triggering a catastrophic collapse.
- This must therefore be prevented at all costs.
United States

High levels of calcium chloride found in collapsed bridge grout
Palau
Belgium
Belgium
Particular Concerns Arise When:-

- The grouting of ducts are incomplete
- The air is moist
- Water is available
- Salts can enter the system
In-complete Grouting
Air is Moist
Water is Available
Salts Can Enter the System
The Hong Kong Bridge Stock

The potential problems of Hong Kong’s bridge stock are:-

- Most bridges are influenced by a marine environment
- They experience very heavy summer rainfalls
- Very few bridge decks have waterproof membranes
- The climatic conditions can be very humid that can assist the carbonation of concrete
- Many viaducts have simply supported spans with leaking bridge joints
The Hong Kong Bridge Stock

– Many viaducts have half joints details that are very difficult to inspect and maintain
– The structures are heavily trafficked
– Post-tensioned segmental constructed structures can be vulnerable at their construction joints
– During periods of high construction boom it is, unfortunately, a fact that workmanship and supervision qualities fall (50% of HK’s Bridge stock has been constructed over the last 10 years)
Historic Reasons for the Problems

- Early post-tensioned structures suffered from the following:
  - Poor workmanship, particularly in grouting activities especially using spacers within the ducts and with untrained staff
  - Poor detailing, poor quality of joints on segmental construction, fragile vent pipe details
  - Poor supervision, especially when high volumes of work were required
  - Poor structural waterproofing
Historic Reasons for the Problems

– Poor quality of grout specifications with high water/cement contents and few admixtures
– Grouts suffered from high shrinkage and water lenses often occurred
– With time the water evaporated leaving voids within the ducts
– When fresh cement was used some grouts suffered excessive heat generation, hardened prematurely and stopped the continuous flow of grout through the duct
Poor Grouting – 1960’s
Poor Grouting – 1970’s
Poor Grouting – 1980’s
Poor Grouting – 2001
The Vulnerable Locations Are:-

- Joints in segmental construction
- Construction joints
- High points in tendon profiles
- Low points in tendon profiles
- Anchorages
The Need for Effective Inspection and Monitoring

- To give bridge owners confidence that their post-tensioned bridge stock is in good and a safe condition it is essential to implement effective Inspection and Monitoring regimes of Post-tensioned Bridges
- A comprehensive and logical approach is required
The Need for Effective Inspection and Monitoring

- From the UK’s experience the following Advice Notes were developed for managing a Special Post-tensioned Bridge inspection programme

- The main documents being:-
  - Prioritisation for inspection (BA54/93)
  - Planning and execution of the inspection (BA50/93)
Special Post tensioned Bridge Inspections

- The initial inspection programme of a particular bridge stock is based on a priority ranking system.
- In the UK the priority ranking system is based on the following attributes:-
Special Post tensioned Bridge Inspection

- **Bridge Factors** - Age of the structure
  - Structural form
  - Presence of vulnerable details

- **Site Factors** - Traffic on the bridge
  - Traffic under the bridge
  - Strategic importance of the route

- **5 No Priority Ratings** - 1 (Highest) to 5 (Lowest)
  (Note:- The highest priority to be inspected first)
Special Post tensioned Bridge Inspections

Phase 1: Desk Top Study

- To determine the fundamental design and construction details
- To review previous inspection and maintenance records for the bridge
Special Post tensioned Bridge Inspections

Phase 2 : Preliminary Site Inspection

- To verify design and construction details
- Identify any signs of distress
- Plan appropriate investigation programme
- Produce a “Technical Plan”
Special Post tensioned Bridge Inspections

Phase 3 : Detailed Site Investigation

- Corrosion detection
- Sampling
- Material testing
- Void detection
- Void volume measurements
- Internal examination of voids
- Stress determinations
PHASE 3 - SITE INVESTIGATION

Site Investigation

Corrosion Detection Sampling

Void Detection Internal Examination

Is Further Testing Required

Yes

Material Tests

Voids

Tendons

Stress

Conditions

Load Testing

No

Further Tests ?

Yes

No

Project Manager's Report
Cover Meter with Probe for Duct Locating
Radar Survey Locating PT Ducts
Video Inspection of PT Ducts
Void Determination
Half cell Potential Survey
Resistivity Measurements

Concrete Resistivity Measurements

Indication of probability of corrosion
Chloride Determination

CONCRETE DUST SAMPLES FOR CHEMICAL ANALYSIS

LEVEL OF CHLORIDE CONTAMINATION INDICATES LIKELIHOOD OF PITTING CORROSION
Insitu Stress Determination - Concrete
Instu Stress Determination - Tendons

Strain gauges with 1.6mm diameter, 1mm deep hole drilled in tendon
Managing Problems Identified

- Re-grouting existing voids to ducts
- Adding external post-tensioned tendons
- Adding carbon fibre plates or fibre reinforced polymers
- Installing suitable propping systems to prevent catastrophic failures occurring
  - Note, such propping system will not be utilized until a structural failure occurs
Additional External Post-tensioning
Carbon Fibre Plate Strengthening
Improving Existing Bridge Durability

- Installing bridge deck waterproof membranes
- Re-place leaking bridge joints
- Re-move bridge joints and make the structure semi-intregal
- If having semi-intregal abutments construct inspection galleries
- Apply suitable waterproof coatings, i.e. silane
- Install permanent corrosion monitoring systems
The Importance of Bridge Deck Waterproof Membranes
Taf Fawr Bridge

The deck is in the form of a box girder with four webs; is continuous over three spans of 127 ft., 216 ft., and 127 ft., and is anchored at the east abutment.
Taf Fawr Bridge Durability Defects

- Severe local damage had occurred to the precast concrete units.
- Severe corrosion was occurring to the reinforcement and the tendons contained within the precast units.
- There was a 30% loss of prestress in the bottom flange.
Taf Fawr Bridge Demolished in 1986
Clifton Bridge
NOTTINGHAM

Clifton Bridge is a prestressed concrete structure crossing the Trent at an angle of skew of 24°. It has a main span of 275 ft. comprising two 87 ft. 6 in. cantilevers and a 100 ft. suspended span. Three 90 ft. viaducts, two 125 ft. end spans complete the structure, which is 800 ft. long.

At the time it was completed, the bridge was the longest prestressed concrete single span in the country. It fulfilled an urgent need for an additional crossing of the River Trent, and provided direct access from the city to a very large housing estate developed at the village of Clifton. It remains one of the most beautiful bridges built in this decade.

The method of construction was of considerable interest. The cantilevers were constructed by cantilevering out in 10 ft. sections using a moving scaffold suspended from the previously completed section. It was the first time this method had been adopted in this country.
Clifton Bridge

- Major refurbishment carried out in 1994
- Corrosion damage to post-tensioned tendons located in the top of the deck
- An ineffective waterproof membrane caused the problem
Previous Waterproofing Problems to Hong Kong Bridges

The reasons for the failures:-

- Low adhesion between waterproof membrane and bituminous surfacing
- Reduced pavement thickness
- Use of open grade friction course
- Premature aggregate stripping
- Mix design of wearing courses
- Inadequate compaction
Previous Waterproofing Problems to Hong Kong Bridges

- Weak friable aggregate
- Excessive dust coating on aggregates
- High ambient temperature
Solutions to these Problems

- The minimum structural thickness to the pavements to be 100mm i.e. binder and wearing course to be 100mm
Solutions to these Problems

- The waterproof membrane to be used is to have a stiff modulus of elasticity
- The waterproof membrane must not be thicker than 2.5mm
- The bridge deck needs to have sub-surface drainage facilities
- The tack coat to the waterproof membrane needs to be of a bitumen “thick” type and be polymer-modified
Solutions to these Problems

- The Binder needs to be a polymer-modified Hot-Rolled Asphalt (typically 35% Aggregate Content)
- The Binder must be laid at a temperature high enough to activate the tack coat
- The Binder must be well compacted and have a voids content no greater than 4 to 5% at the Membrane/binder interface
Solutions to these Problems

- The wheels of the paving machine needs to be clean at all times and not disturb the laid tack coat.
- The Binder / regulating course must have a thick polymer-modified bond coat at their interface.
- The primer coat to the surfacing wearing course needs to be thick and polymer-modified.
New Materials

- Gussasphalt
- Waterproofing system and combined pavement system
Replace waterproofing layer and surfacing every 30 years.
Hot Rolled Asphalt \[ \Sigma \text{LCC} = 1.26 \]

Replace waterproofing layer and surfacing every 20 years
Asphalt Concrete

\[ \Sigma \text{LCC} = 1.45 \]

Replace waterproofing layer and surfacing every 15 years
Reinhard Wirths

Transportation Infrastructure – Life Cycle Perspective

- **Gussasphalt**
  - \( \Sigma LCC = 1.00 \)
  - Replace waterproofing layer and surfacing every 30 years

- **Hot Rolled Asphalt**
  - \( \Sigma LCC = 1.26 \)
  - Replace waterproofing layer and surfacing every 20 years

- **Asphalt Concrete**
  - \( \Sigma LCC = 1.45 \)
  - Replace waterproofing layer and surfacing every 15 years

Costs [%]

Time [years]

Costs [%]

Time [years]

Costs [%]

Time [years]
STEEL - DECK

- Stone chippings
- Wearing Gussasphalt AE PS 8/11 30 mm
- Base Gussasphalt AE - S 8/11 30 mm
- Tack Coat
- Eliminator Membrane (2nd coat) 3 mm
- Eliminator Membrane (1st coat)
- Concrete or Steel Primer
- Shot blasting
- Steel - Deck 10 mm
CONCRETE BRIDGE - DECK

- Stone chippings
- Wearing Gussasphalt AE PS 11 35 mm
- Base Gussasphalt AE – S 11/16 30 mm
- Tack Coat
- Eliminator Membrane (2nd coat) 3 mm
- Eliminator Membrane (1st coat)
- Concrete or Steel Primer
- Shot blasting
- Concrete
Sub-surface Drainage Details

THE NEW TOTAL DRAINAGE SYSTEM FOR POROUS ASPHALT

With the advent of porous asphalt on bridge decks, the rapid removal of percolated water is considered essential for its own performance and the avoidance of a major driving hazard in wet weather conditions. Conventional kerb side entry drainage systems, although relatively efficient in the collection of surface water run-off, are not specially designed to drain excessive water build-up accumulated within this type of construction.

Although these systems are proven on traditional road surfaces, their use on porous asphalt is ineffective in their present form.

Bridgedeck 3 is the latest development in kerb side entry drainage systems, building on the sound engineering principles of the existing Bridgedeck range. Its innovation now permits the effective collection of water below the road surface from within the porous base and its transportation within a deep, high capacity channel. In addition to the positive relief of surface water, Bridgedeck 3 offers a total drainage capability.

1. Subsoil water run-off via the kerb weir
2. The removal of percolated water from the porous layer
3. Positive drainage at deck waterproofing seal

The results are: improved safety and the minimisation of the risk of premature failure of waterproofing and expansion joint installations.

COOPER CLARKE

BRIDGDEK 3 FOR POROUS ASPHALT
Sub-surface Drainage Details
Re-placing Bridge Joints
Damage Caused by Leaking Bridge Joints
Removal of Bridge Joints
Semi-intregal Solutions

Figure 1(d) Continuity Detailed Type 4 Continuous Separated Slab,

Typical features:
1. Separate bearings and diaphragms are provided for each span.
2. Deck slab is separated from support beams for a short length to provide rotational flexibility.
3. There is no continuity reinforcement between ends of beams and there is no moment continuity between spans.
Provision of Inspection Galleries