Engineering for Aesthetics
The forming of the bridge piers of the Millau Viaduct

ice Ireland
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Tonight’s Menu

- Introduction
- Background
- The Deck
- The Pier Bases
- The Piers
  - The system used for climbing
  - Shape and the challenges in forming it
  - The philosophy behind the formwork engineering
  - On the Way Up
  - The completed Piers
- The Toll Plaza Canopy
- Conclusion
  - What did we get for the money
The Framework of the Presentation

- Background to the bridge
  - Why it was built
  - Where it is
  - Who provided initial design
  - How it came to look the way it does
  - When it started and was finished
  - What it is made of
A75 Motorway link from Clermont Ferrand to Berziers
Satellite Photo of the Trace
Why

- That stretch is missing link in motorway route from Paris to Barcelona
- Before viaduct traffic drove down into the valley and through the town of Millau
- August regularly saw delays of 5 hrs+ in Millau, which gridlocked an entire town
Millau
Background to Design

- Originally designed by Michel Virlogeux whose concept was taken up by Sir Norman Foster’s practise
  - Pont de Normandie
  - Wishbone Pylon and Cable Stay
  - Briefly the longest cable stay span in the world
The slender design of the Virlogeux/Foster Viaduct was chosen but had a contrasting pier design to the Pont De Normandie.

The wide based Wishbone of the Normandie Piers had become a very slender “Y” shape for Millau.

High Level Wind Loads in Valley created a weak point in the wishbone.

One of the Millau piers is 4 times higher than the Normandie piers.
The “Open Hands” Pier Design

- The Single main stem with transition to “Open Hands” deck support gave best accommodation of wind loads in the upper levels of the Tarn Valley.
- The Main Stem is hollow with internal cross slabs.
- The point of bifurcation is solid
- The twin piers are hollow
- Designed for 200km/h winds at deck level
Why was this design chosen

- Slender lines had least impact on environment of the valley
- Visually Stunning
- Had potential to make a striking architectural statement
- Kept traffic right out of Millau
- In March 2001 Eiffage TP won the contract to construct with a 75 year concession to operate (which can be removed if proves too profitable!)
- Deck was curved to a 20km radius to avoid sensation of “dreaming” or “flying”, and to allow sight of all pylons
Don’t trip out at the wheel
The Deck

- Vital Statistics
- What that means for the piers
- Why it is curved
- How it was moved
The Deck

- Is a trapezoidal Box Girder design
- If made from reinforced concrete it would be 7m deep and weigh c. 200,000 tonnes
- By making it in steel, the deck can reduce in depth to 4m, and in weight to 36,000 tonnes
- However, the reduction in dead weight on to the pier heads meant that the deck would need stressing tendons down to the bifurcation point for stability.
- This adds 6,000 tonnes load per pier
- The dead weight of the single pier section is sufficient for stability
More Vital Statistics

- Carries 10,000 tonnes of tarmac on main carriageways and another 4,000 tonnes on hard shoulders
- Each pylon anchoring the cable stays is steel and weighs 700 tonnes
- Each Main Cable can take tensile load equivalent to 25 Jumbo Jets at full thrust
- Steel of the cable stays adds 1500 tonnes to the overall weight
Deck Movement

Hydraulic “Lift and move” Rams - Enerpac
The Movement of the Deck

The Enerpac Rams
Let’s now start at the Bottom

- In order to get from abutment to abutment, 14km of road were constructed including a temporary bridge over the Tarn.

- The Pier Bases
  - Concentrate on Pier No.2 (P2) as this is the tallest
  - Soil is principally Limestone and riddled with caves and fissures containing bacteria used in the making of the region’s main export……..
Roquefort Cheese
Each pier is founded on a plate or base, and four posts or piles.

The piles are each 5m diameter and extend down to a max depth of 14m.

On top is the base itself, which for P2 is 6m deep.

The Initial Launch pour for the pier is conventionally shuttered.
The Base Plate

- As a solid concrete entity, base was too big to tie shutters conventionally so each base shutter was supported with PERI SB Brace Frames anchored into purposely laid rc base
- The piers together required 10,000 tonnes of reinforcement steel
- The bases required 13,450 tonnes of rebar
- The piles required 1,200 tonnes of rebar
- The piles alone used 6,000m$^3$ of concrete
Pouring the Launch Pour
The Piers

- Slender pier designed as “running, tapered octagon”
- Seven no. piers in total, similar shape from deck down, but differing heights
The Pier Elevations

- Each Pier continually tapers in both planes from base to top
- In general, each pier is identical from the road deck down
- For a distance of 90m from the deck, a twin pier is used
- 90m below deck is a transition point where twin pier becomes a single pier
- Pier no.2 is benchmark at 245m high
- All others are “cut from below”
- MUST FIND A WAY TO CLIMB FORMWORK
How To Construct the Pier

- It was decided to pour the pier in 4m lifts using a climbing form system.
- Ideally it would go something like this.
So how do we climb? - We asked an Expert

- An automatic rail climbing system (ACS)
- Formwork Shutter and Work platforms are integral
- Hydraulic Rams push shutter and carriage up the rail
- Rail runs through shoes fixed to concrete
- Rams lift rail up when carriage is fixed in position
Basic System Used Worldwide

Petronas Towers

Andromeda Tower

Weichsel Bridge Warsaw
Mega Bridge Bangkok
Sharq Building Kuwait
And Many More............

North Danube Bridge, Hungary

Turning Torso, Malmo
And at Millau
Section Through a Complete External Climbing Unit

- Pouring Platform
- Lattice with suspended formwork elements
- Self climbing system ACS with hydraulic ram (caterpillar)
- Struts punch against wall
- Rail
- Climbing Shoe
- Finishing Platform
One Complete Lift of the Shutter and Carriage
How the Rail is Lifted
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The Anchors
Advantages of the ACS System

- Self Climbing – Can climb without crane
- Carries the shutters on retracting carriage so all shutter work can be done “on board”
- Carries follow up platform for “finishing off” tasks
- Can operate in 180km/h winds
- Acts as windshield for rebar fixing and internal work
- Allows all shutter modifications
ACS is a self contained system that allows pure repetition of procedure with each climb, simplifying high rise concrete construction, and offering tremendous speed of turn round.
Advantages of 4m lift heights

- Straightforward shutter maintenance on deck
- Easier control of concrete pours
- Highly accurate plumbing of shutters
- Greater adherence to performance tolerances
- Optimum positioning of ties
  - One level in pour means less hole plugging
- Allows 3 day pour cycle.
- Allows maximum repetition of procedure – actually very logical
Strict Formwork tolerances

- All edges are sharp and straight
- No horizontal board lines within the 4m pour
- Minimum no. of Ties and regular tie pattern and level
- Regular and unobtrusive anchor pattern
- 0.5mm tolerance on vertical panel joints
- Max allowed 5mm deflection over 2m length of shutter face plate
- Trapezoidal inverse beading delineates pours
The concrete and the shutter

- **60N/mm strength**
- **Generated face pressure on shutter of 100kN/m²**
- **Reduce ties by tying over top of pour**
- **Consequently use steel faced and backed shutter**

Waler for Tie positions
Running Taper design means pier footprint changes dramatically
- P2 starts at 27m x 18m and tapers to 14.4m x 16.13m in single section
- Twin section tapers from 14.4m x 16.13m to 11m x 15.5m
- Need formwork system that can accommodate that change in layout
- With a pier involving over 60 pours, each one is different!!!!!!,
- Each subsequent pour is 4m further off the ground
The Changing Face of the Formwork
In Conclusion, the challenge is........

- To take a system based on repetition and use it on a job with NO REPETITION in the climb whatsoever.
The Shutter - How do we cope with changing Geometry?

- Adaptaptability –
- Identify areas that remain Constant
Viaduc de Millau

- Description of the formwork solution
  - External Formwork
External Shutter Adaptation

Telescopic Waler

Sliding Corner

Adaptation to the geometry
Telescopic Waler

Rear of Steel Shutter

Telescopic steel waler in compensation area
Shutter rises and closes (exaggerated)
Corner Closes (exaggerated)
Sliding Corner
The Corner Pieces

Articulated corner connection

Corner connection in compensation area
The Platforms need to Adapt Also

Telescopic area

Removables
Internal Climbing System

- Every 8 lifts a concrete cross slab is cast internally
  - Prevents continued use of rail climbing system
- Use conventional crane handled “jump” form system
  - PERI SKS
The issues of adaption remain, but here the crane is used to lift units up and occasionally out.
Major Internal Adaptions

- Can crane entire units out for modification
The Twin Pier Section
Twin Pier Platforms

- Externals
Twin Pier Sections

- Internal
Don’t Forget Your Packed Lunch !!!
The Finishes
The Concrete Finish on the less exposed faces
What was Used

- 3 complete sets of formwork and climbing kit for single pier structures (External)
- 3 sets for above (Internal)
- 3 complete sets for twin pier structures (External)
- 3 Sets for above (Internal)
- 1 complete set for the transition area from single to twin pier (Internal and External)
- Kit moved from pier to pier as programme needed
- 6.5km\(^2\) of formwork face
- 196 ACS Frames
- 96 SKS Frames (Internal)
- 12 special frames
Design Demands

- For those of you who like paperwork.........
- 800 Formwork Drawings
- 100 Assembly Plans
- 200 Method Statements
9th December 2003
The world’s tallest piers are all completed
Not to be outdone......

- PERI’s celebrations were a little more modest.........
The Finish on the Exposed Faces
The Peerless Piers
Millau My - What a Bridge !.....
A perspective on the height........

- The Royal Gorge Bridge, Colorado
Identical Philosophy adopted in construction of the Toll Plaza
The “Segment Factory”

- Segments or Elements cast inside factory shutter
- Since segments were to be joined in final construction the neighbouring segment was cast above.
- Used Ceracem instead of Reinforced concrete
The Queen Bee and her Offspring
Pre-Cast Elements
The Finished Article

- A 98m x 28m Concrete Canopy
- Bolted and tensioned Segments
- Locates on 4 pairs of "trees"
- 4km from viaduct
- Stunning Gateway to an inspiring structure
The Millau Viaduct

- 2.46km Long on a 20km radius
- The longest multiple cable stay bridge in the world
- The Tallest bridge piers in the world (244.96m)
- One third taller than the previous tallest
- Tip of the Pylon is 343m high
Timeline

- **16th October 2001**
  - Construction Starts

- **November 2002**
  - P2 reaches 100m height

- **26th February 2003**
  - Deck launch begins

- **28th May 2003**
  - P2 clears 180m to surpass Kochertal Viaduct and become world’s tallest pier

- **November 2003**
  - Completion of the piers

- **26th March 2004**
  - Southern deck reaches P3

- **4th April 2004**
  - North Deck reaches P2

- **28th May**
  - The Decks meet
Its Open at Night, Too
So what do you get for your 400m Euros

- 700,000 visitors in first 9 months
- In summer now gets up to 50,000 vehicles per day
- Of Course, you could always have …………….
A Regional Icon  A Global Structure