From Feasibility studies to Construction Site Design and Construction of Major Bridges

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Former Chairman – IABSE Foundation
Parameters influencing design decisions

- Safety
- Risk Management
- Prefabrication
- Life Cycle Costs
- Life Cycle Manag.
- Natural Resources
- CLIMA - CO₂
- Aesthetics
- Politics
- Environment
- Experience

Structural Bridge Design
Deep Water Bridge Foundations
Integrated Multidisciplinary approach

- Life Cycle
- Safety, Reliability and Risk
- Cost and Time
- Environment
- Transport Demands
- Aesthetics
The Great Belt, West Bridge
Ekofisk storage platform 1973 - Bridge foundation??
The Great Belt - West Bridge

› 324 sub- and superstructure elements

›Prefab foundation caissons

› Onshore assembly line fabrication

› 30 m water depth

› 8000 t max weight of elements

› Placement by floating crane on seabed
› prepared w/crushed stones base course
The Great Belt West Bridge, Denmark
Prefab. element plant, superstructure and substructure
West Bridge
Placement of 110 m Railway Girder
The Great Belt – East Bridge, Denmark
Main span 1624 m
East Bridge, Anchor Block

Permanent effective weight of concrete and ballast: 1905 MN

Cable pull:
- Permanent load 455 MN
- Live load 93 MN
The Great Belt Bridge Anchor structure design
Anchor block – Form follows function
The Oeresund Link, Denmark - Sweden
The Oeresund Bridge, 490 m span rail – road bridge
Prefab foundation caissons
The Oeresund Bridge, Denmark - Sweden
100 % prefab. Piers and superstr.
Floating crane "Svanen" – The Swan
Jacking
Gibraltar Bridge proposal, 3.500 m spans, 300 m water depth
Condeep GBS Bridge Foundation?
Condeep Gravity base offshore platforms
Gibraltar Strait Bridge, Spain / Morocco

Main Spans: 3 x 3,500 m
Pier Concepts (1985)
Ship Collision Studies (1987)
Gibraltar Strait Crossing
(Spain - Morocco)
Foundations

- Deep Water Piers
- Concrete
- Design similar to deep water off shore platform design (Gravity Base Concrete Piers)
600 m tall pylons on 300 m water depth
Gibraltar Bridge proposal
3.500 m spans, 300 m water depth
Yemen – Djibouti Link

29 km bridge connecting 2 cities

By med 4.5 million indbyggere

By med 2.5 million indbyggere
Yemen - Djibouti Link
4 - 2700 m continuous suspension spans

Yemen-Djibouti bridge gets go-ahead
Al-Noor to award build-operate-transfer contract for road and rail link across Red Sea next year

DUBAI: Dubai-based Al-Noor Holding Investment Company said it expects to award a build-operate-transfer contract for the first phase of a bridge linking Yemen and Djibouti in the latter half of next year. The crossing will be the first bridge to link the Arabian peninsula with the African continent.

The total cost of construction will cover the link from the Yemeni mainland to the island of Portor at the Red Sea. Phase two will connect Portor with Djibouti.

The wider project also involves building two cities, at either end of the link. The total investment required for the construction of the cities and the bridge is $2bn. Al-Noor says Al-Noor has already invested an undisclosed amount of its own money in the scheme and remains optimistic that finance will be available to fund the entire project.

Al-Noor has submitted a framework agreement to the governments of Yemen and Djibouti, which needs to be signed before a contract can be awarded.

Al-Noor says an award will happen “definitely in the second half of the year”.

www.meed.com/transport
Study of impact load capacity

ABAQUS model for basic shear strength of 100 kPa Steel piles for ground improvement required: pattern 5.0m and 7.5m

Requirement: 540 MN impact load

Result: 250 kPa needed
Major Technical Challenges

- Very long multi-span suspension bridge
- Water depths up to 300 m
- Wind load / aerodynamics
- Seismic load
- Ship collision
GBS type Foundation Concept
Tiran Strait – Egypt – Saudi Arabia
Tiran Strait Crossing proposal
Egypt – Saudi Arabia
Canal de Chacao
Two consecutive suspension bridges

South

North

Navigation channel
600x45 m

+172

870 m  110 m  1260 m

Towards Ancud

To Puerto Montt

Towards Puerto Montt

To Sea

VSVI - SEMINAR FRIEDBERG, HESSEN 2016
Two-main-span continuous suspension bridge
IZMIT BAY BRIDGE

- World no. 4 - 1550m main span suspension bridge
- High seismic load
- Short construction period – 38 months
IZMİT BAY BRIDGE

General

IZMİT BAY BRIDGE
IZMIT BAY BRIDGE
IZMIT BAY BRIDGE

General layout

- Concrete Anchor Blocks and Tower Foundations
- Tower Foundations at approx. 40 m water depth
- Navigational clearance profile 64x1000m
- South Piers supported on South Anchor Block (Integrated structure)
- Steel towers 250m high
The Bangabandhu Bridge, (Jamuna) Bangladesh
The Bangabandhu Bridge

Max Water Level +16 m
Min Water Level +6 m
Max Bed Level +/- 0 m
Min Bed Level -30 m
Pile Toe Level -72 m

2 Pile Pier
3 Pile Pier

Cast in situ Concrete Pier Stem
Precast Concrete insitu filled Pile Cap

Tubular Structural Steel Piles insitu concrete filled 2.5 - 3.15 m dia

Pile Length 83 m
Padma Multipurpose Bridge project
Padma Multipurpose Bridge
Padma Multipurpose Bridge - Approaches
Padma – Pile driving – Menck 2400 kJ
Padma steel piles – Ø 3.0 m 120 m length
Padma piles w/ internal shear keys
Padma superstructure truss – Lower node fabrication
Padma superstructure truss - Lower node
Dehumidification
The Little Belt Suspension Bridge, Denmark 1970
The Little Belt Bridge, Denmark
Aerodynamic steel box girder
The Little Belt Bridge - Girder segment
Steel box girder corrosion protection
Dehumidification principles

Dehumidification section

T: Trough as air ducts
A: Dehumidifying unit
F: Free airflow
The Oeresund Bridge, Denmark - Sweden
Closed box truss members
The Little Belt Bridge
Dehumidification of Main Cables
Corrosion Protection Systems for Cables

Background for new system:

- Nowadays design lifetime up to 200 years is required (Messina Bridge)
- Life Cycle Costs for bridges shall be minimised
- System is developed based on experience gained from application of dehumidification systems in closed steel box girders
Corrosion Protection Systems for Cables

Dehumidification system:

› Produces dry air and blows it through the cables
› Assures overpressure inside the sealed cables
› Components: dehumidification plants, injection points and exhaust points
Corrosion Protection Systems for Cables

Sealing system:

› Elastomeric wrap for cable sections between cable bands
› Applied under tension with a 50% overlap
› Special details developed for cable bands etc. using combinations of sealer strips and adhesive caulk
Hydraulic stabilisation, damping and actuating systems
The Faroe Bridge, Denmark 1985
First 1700 m continuous steel box girder
Farø Bridge, Denmark, 1985
Continuous steel box girder, 1700 m – soaring "free" through pylon.
Caterpillar with hydraulic actuation
Farø Bridge – Hydraulic control system
Bridge girder torsionally fixed – vertically free
Farø Bridge - Hydraulic cylinder arrangement
The Great Belt Bridge, Denmark
Main span 1624 m
Storebelt East bridge – Articulation
2700 m continuous all welded steel box girder for main span

Sprogø

Zealand

Suspension Bridge

E: Expansion joint  F: Fixpoint

143m  7 × 193m  62m  1556m  11  535m  1624m  535m  11  2518m  140m
The Great Belt Bridge, Denmark
Anchor structure design
East Bridge Anchorblock
Hydraulic damper arrangement
Storebelt East bridge
Hydraulic damper at anchor block
Effect of hydraulic buffer system on acc. movements

<table>
<thead>
<tr>
<th>Bridge type</th>
<th>Continuous length</th>
<th>Maximum movement at joint</th>
<th>Yearly accumulated movement at joint</th>
<th>Relative comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Great Belt East Bridge</td>
<td>2694 m</td>
<td>± 1.0 m</td>
<td>~100-200 m</td>
<td>1-2</td>
</tr>
<tr>
<td>Suspension Bridge</td>
<td><strong>with</strong> hydraulic system (buffers)</td>
<td>2694 m</td>
<td>± 1.8 m</td>
<td>~50 000 m</td>
</tr>
<tr>
<td></td>
<td><strong>without</strong> hydraulic system</td>
<td>2694 m</td>
<td>± 1.8 m</td>
<td>~50 000 m</td>
</tr>
<tr>
<td>Great Belt, Steel Approach spans Halsskov</td>
<td>-</td>
<td>2518 m</td>
<td>~100 m</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td><strong>Steel beam</strong></td>
<td>50 m</td>
<td>±0.03 m</td>
<td><strong>0.05</strong></td>
</tr>
</tbody>
</table>
Store Belt West bridge - Dampers at expansion joints
Bascule Bridges
Hydraulic actuation
Bascule Bridge – Hydraulic actuation
The Messina Bridge, Italy – 3,300 m main span
The Messina Bridge - Triple girder
Messina Bridge, Italy
Expansion Joint and Bearing Assembly
Messina Bridge, Italy
Expansion joint and Bearing assembly
East Bridge, Girder Aerodynamics

Suspension bridge girder

Approach bridge girder
The Great Belt Bridge - Tuned mass damper
Aerodynamic box girders
Airplane wing structure - Aerodynamic box girder
Challenge: Mitigate Vortex Shedding Excitation of Bridge Deck

Traditional mitigation measure
Guide vanes

Wind tunnel test
High Coast Bridge, Sweden

- No vortex shedding excitation
- Vortex shedding excitation appeared

Stall angles for classical airfoils

Conclusion
- Keep angle below 16° to eliminate vortex shedding excitation and avoid installation of guide vanes
- New approach verified by wind tunnel test for Hålogaland Bridge.
The Little Belt Bridge, Denmark, 1970
Aerodynamic box girder with wind deflectors
Great Belt, East Bridge, Denmark 1,624 m main span
Long Span Suspension Bridges
Great Belt, East Bridge
The Great Belt East Bridge - Guide Vanes
The Stonecutters Bridge, Hong Kong
First double box design, 1018 m span
The Stonecutters Bridge, Hong Kong
Double box segment erection
New high performance materials – Fibre reinforced composites and cables
The Messina Bridge, Italy – 3,300 m main span
The Messina Bridge
Wind turbines - Glass- and Carbon Fibre Composites
Herning pedestrian bridge –
Experim. use of carbon fibre stay cables, posttension, and reinforcing
Herning Pedestrian Bridge
Concrete deck with CFRP posttensioning and reinforcement
Herning pedestrian Bridge
16 – Ø 40 mm  37-wire CFRP cable stays
Herning Pedestrian Bridge
Stainless Steel (front) and CFRP (back) reinforcement in deck
Bascule bridge – Composite deck
Bascule Bridge – Composite deck
Pedestrian Bridge – Composite Deck
All prefabricated - installed in one piece
Pedestrian Bridge – Composite Deck
Pultruded Composite bridge truss elements
Active control of bridges
The Messina Bridge
Great Belt, East Bridge, Denmark 1,624 m main span
Sutong Bridge, Jiangsu Province, P.R. China
500 m single box cantilever erection
Stonecutters Bridge, Hong Kong
Double box segment erection,
Suspension Bridge – Critical erection phase
East Bridge, Girder Aerodynamics

Suspension bridge girder

Approach bridge girder
The Great Belt East Bridge - Guide Vanes
Control surface (elevator) autopilot controlled
Active Control system
Moveable control surfaces

Individually Controlable Moveable Flaps
Airbus 380 with autopilot - 4 x redundancy
Elevator control surface - controlled by autopilot
Autopilot – fully digital
Extreme Bridge Spans
variable geometry active control – Leading and trailing girder edges
Box Section - no Flutter Control
2DOF motion
Fixed flaps

t = 0.05
Box Section with Flutter Control
2DOF motion
Moving flaps
Effect of Moving Flaps

Fixed Flaps

Moving Flaps

$t=0.05$
Concluding remarks

• Look across borders to other industries for new ideas which may lead to real major leaps in innovation
• Go to conferences outside the normal bridge field to seek inspiration
• Take the Multi-disciplinary Systems approach
• Be open to news ideas
• Be curious!!
Thank You!