IABSE Danmark Konstruktionspris 2021

LILLE LANGEBRO

Client:	Realdania By&Byg
Bridge Engineer:	Buro Happold
Architect:	Wilkinson Eyre
Main Contractor:	Mobilis Danmark – Hollandia Infra I/S
Completed:	14th August 2019

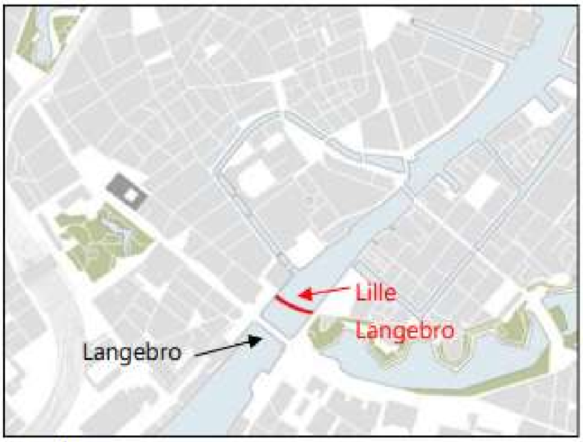
1. Introduction

The Lille Langebro is the latest movable bridge to be built across Copenhagen harbour. Its elegant design was chosen following an international competition and incorporates complex geometry, demanding excellence in structural design and detailing.

The concept is for a low-level structure inspired by the wings of a bird as they flap up and down in flight. This also made sense from a structural perspective as the maximum section depth was provided at the locations of highest demand.

The bridge consists of four sections, two of which rotate in plan to provide the navigation clearance. In order to maintain a slender profile in elevation, an innovative moment connection has been designed to connect the moving parts together at midspan. The four bridge sections were prefabricated off site and delivered to site by sea.

The bridge is prominently situated and has already become a high profile and important artery for pedestrians and cyclists. It was officially opened to the public on 14th August 2019.



Location

Concept

Overall length	166	m	Steel tonnage	456	t
Plan area including structure	1734	m^2	Steel weight density	263	kg/m^2
Usable width	7	m	Equivalent carbon content	650	$kgCO_{2e}/m^2$
Cycleway width	4	m	Construction budget	90,000,000	DKK
Footway width	3	m	Cost per sq.m (2015)	51906	DKK/m^2
Navigation channel width	35	m	Cost per sq.m (2015)	5191	GBP/m2

Data

2. Sustainability

Sustainable development meets present needs without compromising the future. The Lille Langebro project was progressed with this aim in mind. Relevant aspects of its design and construction are as follows:

- A form of construction with a varying depth that responds to the structural demands at any given point along the bridge, thereby adding interest whilst making the best use of materials.
- Central moment connection – allows the bridge to be slenderer and more material-efficient than a traditional locking-pin connection
- Counter-balanced swing mechanism – requires relatively low power to allow the bridge to turn
- Quiet in operation – means bridge does not adversely affect its environment
- Robust design – provides security against accidental actions e.g. ice loading and vessel collision
- Segregated pedestrian and cyclist lanes – greater traffic safety
- Future-proofing - allows increasing pedestrian/cyclist use over time
- Durable design - reduces maintenance over the 120-year lifetime through the use of high specification materials/components.
- Largely off-site manufacture - minimises the environmental impact of construction.
- Deconstruction method - a straightforward reversal of the installation process.

The bridge is operated from a console within the control tower of the adjacent Langebro. Power is also supplied from this bridge, with a network of underwater cables on the seabed providing the connection to the piers of the moveable spans.

Bridge operated from control tower

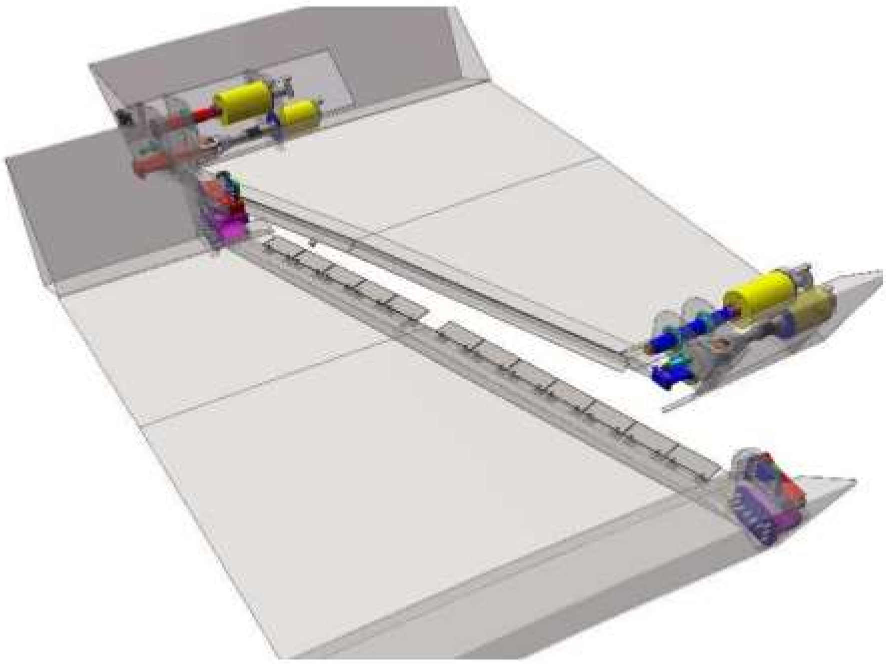
3. Creativity/Innovation

To maintain a slender elevation, an innovative central moment connection (CMC) connects the moving parts at midspan. This connection clamps the sections together and allows longitudinal temperature expansion/contraction. The clamping action means the bridge is much stiffer and less prone to vibration than if it were pinned in the middle.

The moment connection is achieved via paired hydraulic cylinders located within each of the two bridge box girders mounted to internal diaphragms. The upper mechanisms generate compressive resistance whilst the lower mechanisms generate a tensile force. When engaged in its socket, the compression mechanism also provides shear continuity and vertical alignment of the two moving spans.

The tension and compression elements within each beam are hydraulically connected in such a way that, as the vertical load increases on the bridge, so does the pressure in the cylinders generating the moment resistance. However, as the bridge expands and contracts thermally, the tension and compression elements will expand and contract with the deck by moving oil from one cylinder to the opposing one. This allows the effective release of static axial loads at the connection which significantly reduces the horizontal loads and resulting moments acting on the bridge piers and foundations.

Under dynamic pedestrian excitation the moment connection acts as an effective viscous damper as the restricted flow rate of the hydraulic oil is slower than the frequency of the loading cycle. Therefore, the connection is effectively axially restrained under dynamic loads. This significantly improves dynamic performance, keeping vertical accelerations within comfort levels and avoiding any additional damping.



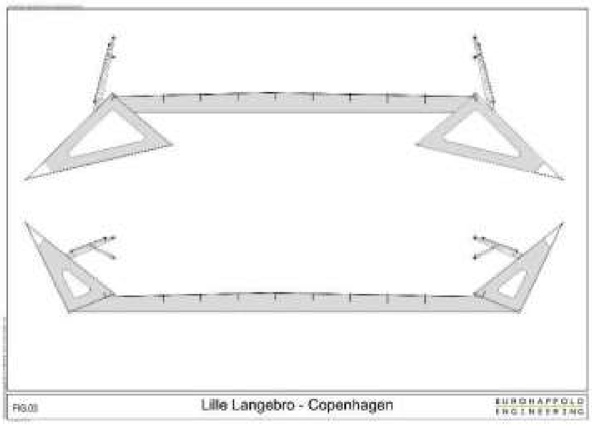
CMC

4. Elegance/Detail

The design of the bridge is characterised by attention to detail. Some examples:

- The plates forming the main longitudinal edge members incorporate double curvature due to the complex geometry meaning the structural design of the boxes and their internal stiffness was heavily influenced by fabrication practicalities.
- A key visual feature of the bridge is the outer corner of the boxes and great care was taken with detailing this area.
- An orthotropic deck spans between the outer members. Longitudinal stiffeners follow the sweeping path of the bridge, adding interesting views of the soffit.
- The four bridge piers are formed within cofferdams and consist of concrete structures founded on limestone. These structures are robust enough to resist high ice loads. A secondary vessel collision protection system has been provided either side of the 35m wide navigation channel in order to contain ships.
- The bridge mechanism is visually concealed. The motors and slewing ring are housed within the hollow bridge piers. Hydraulic power units are housed in cavities inside the outer deck members. Enlarged chambers are provided adjacent to the moment connection for the hydraulic rams and associated mechanical parts.
- The bridge parapets are a bespoke design consisting of rails housing light fittings to provide illumination to the deck as well as architectural feature LED lighting of the outer edges of the bridge. They are infilled with stainless steel mesh and have an undulating profile to accentuate that of the steelwork.

The quality of fabrication was assessed directly at the tender stage by full scale prototypes.



Cross section at (i) end (ii) midspan

Prototype

5. Value

The design team set out to provide an economical design with a structure that provides interest through its form rather than by any embellishments/cladding.

With a construction value that works out at £5190/m2 , the Lille Langebro compares well with the median cost of c. £6,300/m2 reported in a 2011 study of costs for typical landmark footbridges[1] even though it is a movable rather than static bridge.

Its non-financial value is considerable too. The bridge provides a safe and convenient route for pedestrians and cyclists who previously had to use the adjacent bridge which has high traffic volumes, narrow footways and no dedicated cycleways. There are approximately 40,000 commuter cyclists who use the route every day.

The centre of the bridge is elevated relative to its ends providing enjoyable views of the city and harbour. It attracts visitors and brings considerable benefits in terms of regeneration and connectivity of the local area, tapping the potential of the inner harbour area by enhancing urban life and vibrancy on the waterfront. It also directly serves the Client's Blox project, which includes cultural facilities, offices and homes, at the west end of the bridge.

The bridge was gifted to the people of Copenhagen by the Client on completion.

6. Constructability

This excellent project has been achieved by close cooperation and frequent team workshops, which has brought out the best of the design-and-build set up. The result is a high-quality structure that all involved are proud of.

The bridge sections were prefabricated entirely off-site and delivered in a completed state by sea. This approach meant improved quality in factory conditions rather than on site, better safety and less susceptibility to weather delays.

A high standard of workmanship was essential to successful delivery. It was vital that the tolerances in fabrication of steelwork and placement of foundations were fully considered by the design/construction team. Great lengths were taken to investigate the possible thermal effects on the bridge, using a detailed analysis based on a shading study at all times of day throughout the seasons of the year.

Analysis model

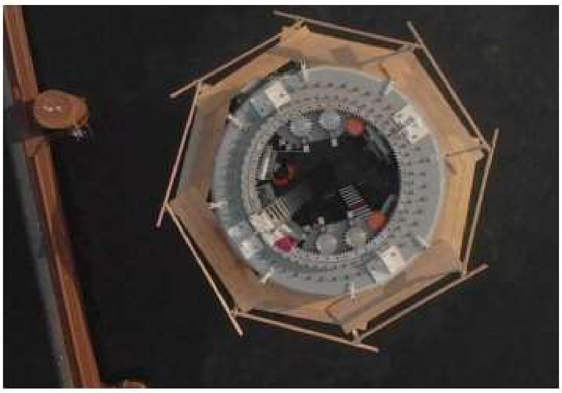
[1]Duguid B., Benchmarking Cost and Value of Landmark Footbridges, Footbridge Conference 2011, Wroclaw

A jig was built for the steel assembly and individual plates were first accurately bent to the correct curvature. The fabricated geometry was adjusted using pre-sets to account for permanent deformations. As most welding was below the bridge, it was assembled upside down and then turned over with a crane.

Flipping of bridge

A full trial erection was undertaken at the workshop, including balance tests of the rotating sections. Factory bench tests were performed on the hydraulic-electrical systems.

A large capacity shear leg crane met the delivery barge and installed the bridge sections onto its supports. The entire transportation/erection operation took only 10 days.



Bridge mechanism

Installation

7. Conclusion

The project has required close cooperation between all parties to deliver a complex structure to a high standard. It is particularly notable for a number of reasons:

- A unique and inspiring bridge concept
- The innovative central moment connection
- Outstanding fabrication quality and attention to detail

A short video is available at the following link: https://vimeo.com/374901998

Completed bridge