HEAVY MOVABLE STRUCTURES, INC.
NINETEENTH BIENNIAL SYMPOSIUM

October 16-20, 2022

An Innovation in Swing Bridge Design

Michael Thorogood
Eadon Consulting Ltd (UK)

RENAISSANCE ORLANDO AT SEAWORLD
ORLANDO, FLORIDA

Summary

The Lille Langebro (Little Langebro) pedestrian and cycle swing bridge opened to the public in August 2019. The bridge provides a quay-level crossing of the harbour for pedestrians and cyclists and was the outcome of an international design competition. In order to enable the passage of marine craft along the harbour the central sections of the bridge rotate. This paper gives a brief overview of the operating equipment associated with the movement of the two rotating spans before a more detailed discussion on the innovative moment connection developed to secure the joint between the two moving spans when in the bridge closed position.

Introduction

The Lille Langebro swing bridge was the winning design from an international design competition commissioned by Realdania. The design team consisted of structural engineers Buro Happold, architects Wilkinson Eyre, mechanical engineers Eadon Consulting and landscape architects Urban Agency. The bridge was built by a joint venture consisting of Mobilis Danmark and Hollandia Infra.
The design takes an ambitious form which required close collaboration between all design parties to ensure full integration of all the engineering disciplines with the architecture.
The bridge is a 160m long, 7m wide, steel superstructure formed by two twisting triangular main members supported to achieve five spans, the central of which opens to allow the passage of vessels. The arrangement and orientation of the triangular members is such that at the centre of the bridge a navigation clearance 5.4m high and 20m wide is provided in the closed position. To achieve this the two main triangular members are above the deck level whereas towards the abutments the structure is below the deck and the triangular cross section is shallower (Fig. 1).

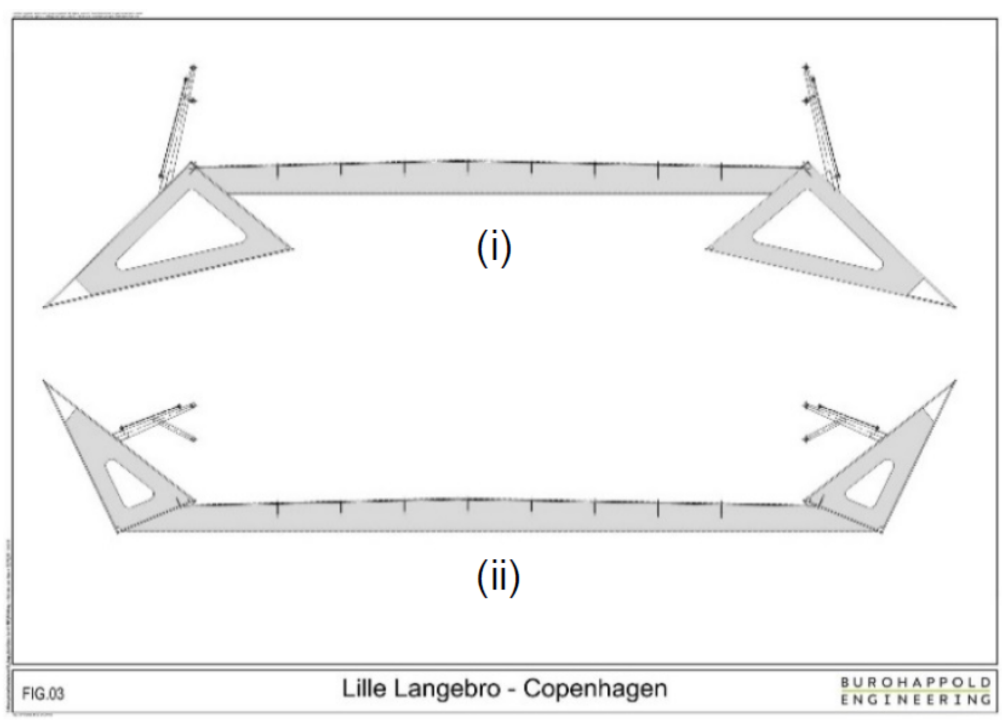

Fig. 1. Cross section of bridge

(i) at ends & (ii) close to mid span. Source: Buro Happold

Bridge operating equipment

Bridge Control position

The neighbouring bigger brother to Lille Langebro, the Langebro, has a historically and architecturally significant control building. The orientation and views from this building are such that they give an excellent direct line of sight for the Lille Langebro (Fig. 1). For this reason, the designers opted to use some of the space available in the Langebro control room to house the communications, CCTV and bridge control desk needed for the new bridge.

Fig. 1. Langebro control tower (left) and view from control position (right): Source Eadon Consulting

Rotation

In order to allow larger vessels to pass the bridge the two central spans rotate about two hollow concrete piers to achieve a 35m wide navigation clearance of infinite height.
At the top of each of the two concrete piers is a thick metal plate to which a roller element slewing bearing is mounted. The moving decks are attached to the top of the slewing bearings. The slewing bearing is equipped with integral gear teeth which are driven round by multiple electrical motors. The motors are driven by motor controllers located within the piers, the signals to control these are located in the Langebro control tower and are connected via an underwater hardwired link.

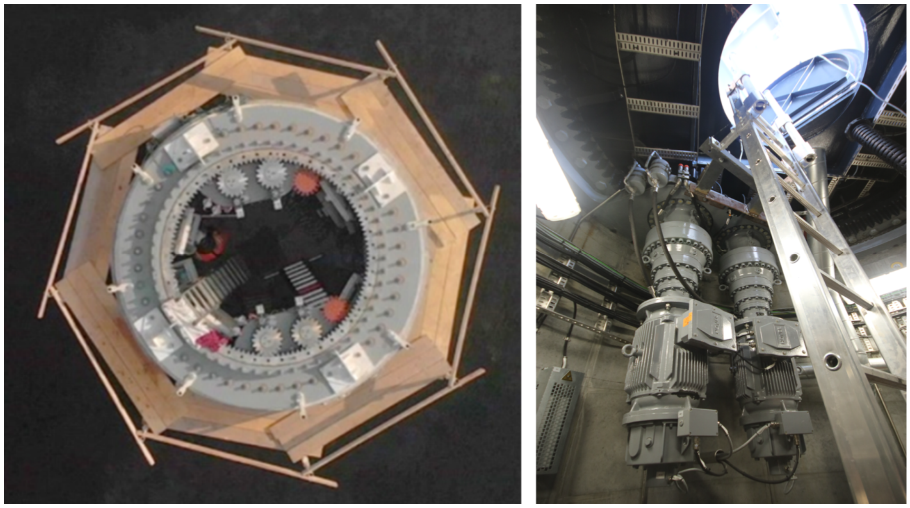

Fig. 2. Arial view of pivot pier during construction (L) View from within the pier with deck installed (R). Source: Buro Happold (L) Eadon Consulting (R)

Deck to deck interfaces

There are three joints along the length of the bridge, two of these are where the tail of the moving spans interface with the static approach span and the third is where the two moving spans meet at the centre. At each interface it is critical that the deck is aligned both vertically and horizontally to ensure that there are no trip hazards and that the architectural lines of the bridge are continuous.

Tail supports

When unsupported in the rotating position the tails of the two moving spans deflect downwards due to dead load but can also move vertically due to thermal effects. In order to provide vertical alignment at the interface between the moving spans and the static approaches a passive (i.e. with no automation or power) mechanism was installed just inboard of the two main members. The design team were keen to avoid unnecessary automated equipment and hence a set of wheels was mounted on the moving span. As the bridge rotates back to the closed position the wheels roll between a pair of plates shaped such that the gap between them reduces as the wheel travels through them. Due to the live loads that could occur when the bridge was closed the wheels were arranged in pairs and mounted on a bogie so that their size could be kept within the depth of the deck section.

Fig. 3. View of tail wheels (deck flaps were propped up during commissioning). Source: Eadon Consulting

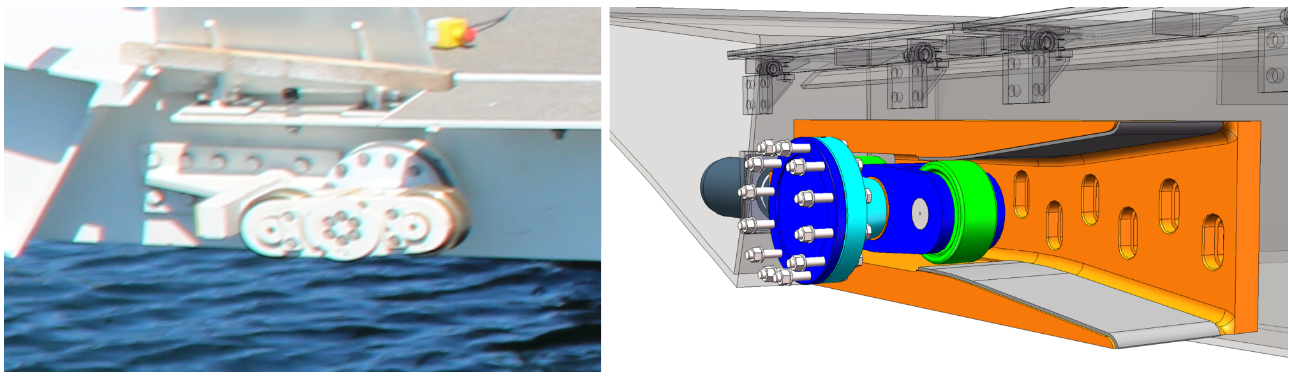

Fig. 4. Close up of tail wheel (L) and 3D model of wheel engaged with socket on static span (R). Source: Eadon Consulting

A hydraulic shock absorber is positioned at the end of one of the rolling tracks so that the tail of the bridge is brought to a controlled and repeatable stopping position at the end of the closing cycle.

Deck flaps were installed to cover the joint between the static and moving spans and to enable them to expand and contract without creating a gap or tripping hazard. The radius of the curved joint was set so that it was not concentric with the axis of rotation so that the deck flaps swing round and the joint closes quickly without the flaps having to slide along the full joint before being in position.

Moment connection

A key innovation that was developed for the Lille Langebro project is the moment connection found at the joint between the two moving decks.

Why the moment connection was developed

The moment connection was developed to carry moment at the joint between the two moving decks and provide vertical and horizontal alignment.

A key requirement of the client's brief was that there were to be no locking pins used on the bridge. Because of the architectural shape of the bridge and the required depth of section at mid span a method of carrying moment between the two moving spans was needed. Double span swing bridges are fairly unusual and when they are built they do not usually carry moment through the moving joint. Previous twin span swing bridges carrying moment used large pins. Because locking pins had been prohibited by

the client due to known reliability issues with these items of equipment the design team had to find an alternative way of locking the two decks together in a way that could not jam like a locking pin but that was simple and robust.
The connection also needed to act as an expansion joint, to allow for thermal expansion and contraction of the separate halves of the bridge. With a traditional locking pin, as the deck expands and contracts the pin has to slide in its socket. If the pin is taking moment this socket has to be deep and close fitting. This can cause the pin to become jammed or result in high loads at the supports. In the case of a twin swing bridge the supports that would see the thermal load would be the sensitive pivot bearings.

What the moment connection consists of

The moment connection is located within the two triangular main beams. Any structural member that carries moment has a portion in tension and a portion in compression. For this reason each moment connection assembly consists of two key elements;
A compression element
A tension element.
The compression element is located within the top of the triangular beams whilst the tension element is at the bottom. Due to the size of the equipment and the triangular cross section ‘blisters’ were created in the beam to accommodate the moment connection.
The compression assembly consists of a compression pin with a cap that engages with a shallow socket.
The tension assembly consists of a square C-shaped mouth and a T-shaped element that rotates into the mouth of the C when the bridge swings back into the closed position.

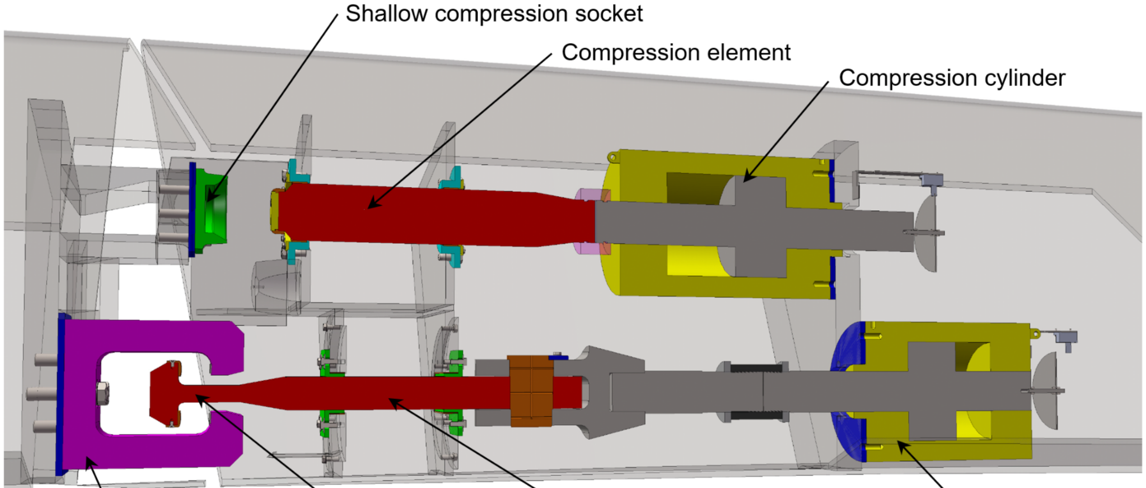

Fig. 5. Cross section through moment connection. Source: Eadon Consulting

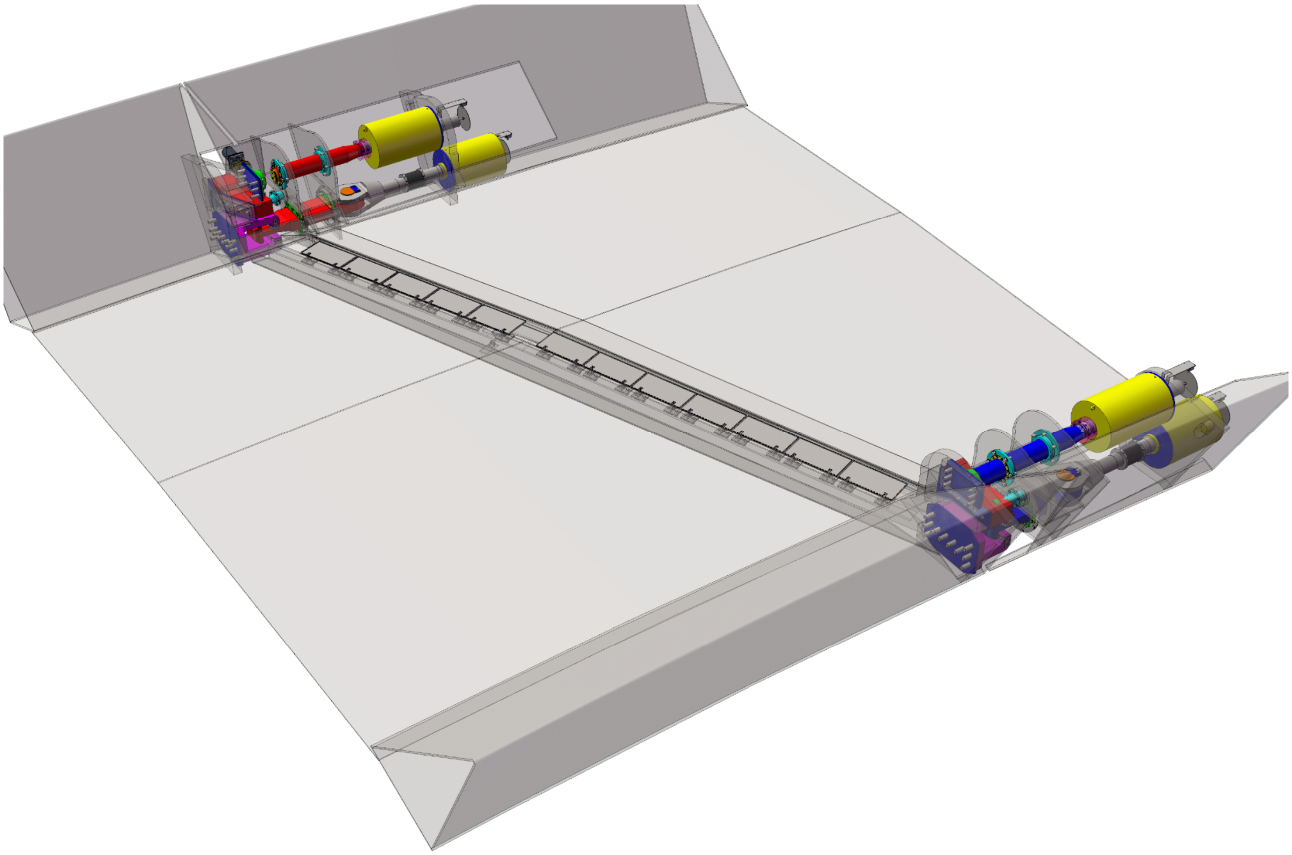

Fig. 6. Assemblies installed within the deck beams. Source: Eadon Consulting

The tension and compression elements are connected to large bore hydraulic cylinders to enable the compression element to move axially by 260mm and the tension element by 150mm. A key requirement is that the two cylinders have identical bore diameters (i.e. the internal diameters of the cylinders) and rod diameters (the portion the moves in and out). This means that they can both push and pull with the same force and both displace the same amount of oil when they extend or retract by the same amount.

The hydraulic cylinders are powered by an electrically driven hydraulic power pack local to the moment connections in each beam. The control equipment for the hydraulic power packs is located within the pivot piers.

The disengaged positions of the tension and compression elements is monitored by the control system. The contact of the locking pin with the target socket is also monitored.

How the moment connection works

The moment connection works by providing a nominal compressive preload at the top of the beam via the compression element and the same force, but in the opposite direction (i.e. tensile load) at the bottom of the beam.

When closing, the west moving span reaches the fully closed position first, and the east span then returns to the closed position. As this happens a wheel located between the compression and tension element rolls into a guide to ensure that the two decks are roughly aligned. The tension T-shape swings around with the deck into the C-shaped mouth. The compressive pin is roughly aligned with the shallow compression socket. At this point the connection is only roughly aligned, the tension T-shape and the C-shaped mount are not in contact and neither is the compression pin with the shallow socket (as shown in Fig. 5).

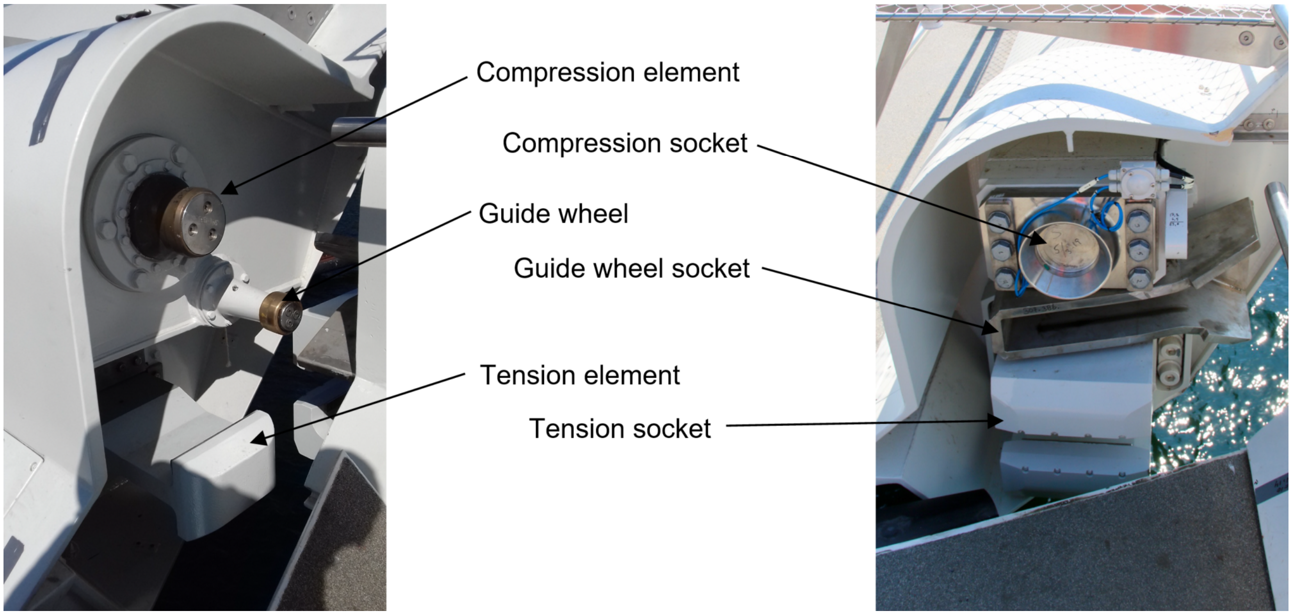

Fig. 7. View on both halves of moment connection. Moving elements (L). Sockets (R). Source: Eadon Consulting

The compression pin extends under low pressure and exerts a force sufficient to provide true alignment of the two decks but without exerting significant force into the other deck. Once the compression pin is sensed to be engaged the tension element retracts so that it is in contact with the C shaped mouth. Once this has occurred the compression and tension elements are engaged but not carrying moment. The pressure in both compression and tension cylinders is raised, and because they are both connected to the same pressure line and have the same hydraulic cylinder geometry, they exert the same force into the opposite deck. A preload pressure equating to a force of 1010kN +/- 337kN is applied. This corresponds to a pressure of between 75 to 150 bar in the cylinders. The two cylinders remain hydraulically connected to each other and the pressure within the system is locked in. The control system monitors the pressure in the cylinders and ensures that it never drops below 10 bar. The moment connection in each beam works independently of the other beam.

Fig. 8. Hydraulic power pack within main beam (L). 'blisters' in beams at joint (R). Source: Eadon Consulting

When the bridge is closed and in use the live load moment is constantly changing. Throughout the day the length of the bridge is also constantly changing due to thermal expansion. The moment connection deals with these two situations without the need for any complex monitoring or hydraulic adjustment from the power pack.

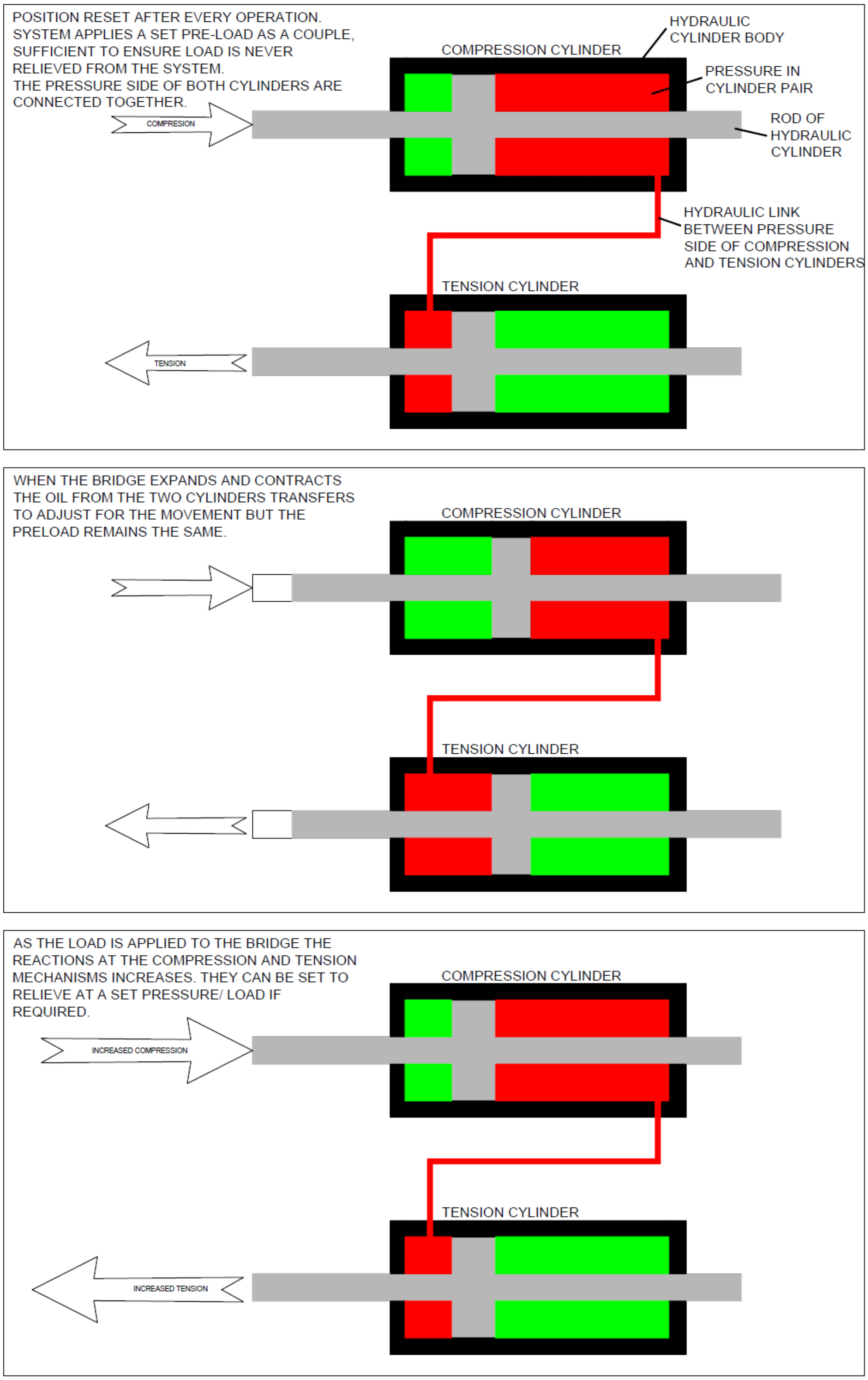

Fig. 9. Process for accommodating expansion and contraction and increased moment. Source: Eadon Consulting

Changes in deck length

Unlike with a locking pin which can jam, thermal movements in the moment connection are accommodated by extension and contraction of the compression and tension elements without an increase in force. If the decks expand thermally and the mechanisms were not able to move the compression element would experience higher compression and the tension element would experience a loss in tension but because the compression cylinder is connected to the tension cylinder as the compression cylinder is forced backwards it brings the tension cylinder with it by displacing oil from one cylinder to the other (Fig. 9.). This means that the load in the system does not change but the compression and tension elements are always in balance.

Change in live load

As live load varies, the joint must carry a varying amount of moment without movement. This is accommodated at the moment connection by an increase in the internal hydraulic pressure of the system (Fig. 9.). This occurs because under increasing live load the compression element experiences increased compression and the tension element experiences increased tension. Because the two elements are connected hydraulically, as one part experiences load the opposing part applies the oposite force to the beam. For example, as the bridge experiences more vertical load the compression element is compressed more, this results in the tension element pulling on the lower part of the beam with the same force. As the load in the beam reduces, the compression in the compression elements reduces as does the tension in the tension element.

Maintaining capacity

One of the key aims when designing the moment connection was to avoid the need for constant adjustment of the system for thermal or live load effects. This aim has been achieved through the linking of the identical bore hydarulic cylinders. This makes the system almost entirely passive; once it has been set at the end of each closing sequence there is minimal need for adjustment. However, as with any hydraulic system pressure can not be locked in indefinitely due to small leakages and oil being able to pass valves albeit very slowly. The control system constantly monitors the pressure within the moment connection and when it falls below a pre-set level of 10 bar the hydraulic power pack activates for a few seconds, reapplies the preload pressure and then switches off again.

Benefits that the moment connection brings

As well as enabling the bridge to carry moment across the joint between the moving decks to enable the architectural vision and the ability to expand and contract without applying additional loads to the slewing bearings, the moment connection also provides a damping effect. Under dynamic pedestrian loading the hydraulic system between the tension and compression elements creates a viscous damper as the flow of oil between the elements is slower than the frequency of the load cycle. The system provides an axial restraint, significantly improving the dynamic performance of the bridge and keeping vertical accelerations within comfort levels.

Discussion and Conclusions

The bridge has been open to the public for more than a two year and has experienced a full range of Danish seasons. There have been no reports of any issues with the bridge operating equipment and in particular none relating to the moment connection.

The development of the operating equipment for the Lille Langebro bridge has resulted in the design of a new solution for carrying moment through an opening joint. This solution has potential uses not only in other moving bridges but also in other structural applications. The passive nature of the design means that the capacity of a joint could be changed to suit the applied load and hence enable more efficient structural designs.

The bridge has gone on to win numerous international awards including the IStructE Supreme Award for Structural Engineering Excellence 2021, RIBA International Awards for Excellence: Winner 2021 and the 2022 European Steel Bridge Award for Cycle and Pedestrian Bridges.