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Innovative Design of Movable Bridges

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Summary

The paper deals with the most outstanding movable bridges designed by Leonhardt, Andrä und Partner during the last five decades: 1 lift bridge, 3 swing bridges, 1 bascule bridge and present a design proposal for a totally new type of movable bridge, the double balance beam bridge.

Keywords: Lift bridge with concrete towers – incrementally launched swing bridge from prestressed concrete – cable-stayed swing bridge – double flap bascule bridge designed against ship impact and earthquake – double balance beam bridge.

1. Introduction

1.1 General

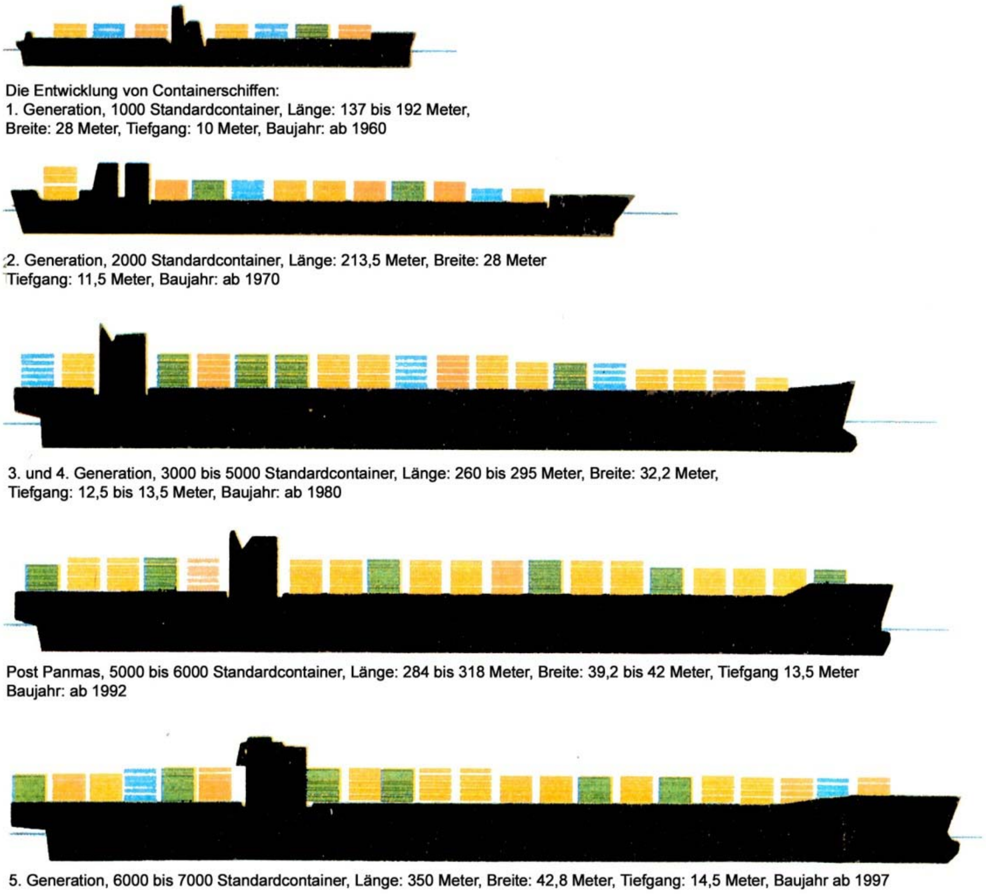
One of the great winners of the globalization is the transport sector, especially the maritime transport. With cost between Fareast and Europe of about

- 2 $ for a DVD-player
- 30 $ for a television set

even the longest way pays off!

This has lead to an explosion-like increase of container traffic, e.g . between 2004 and 2005 in Shanghai by 24 %, in Dubai by 17 % and in Hamburg by 17 % [1].

Consequently, the number of size of container ships has increased permanently, Fig. 1.1 what required to adopt the port infrastructure to the increased ship sizes and truck traffic.



Die Entwicklung von Containerschiffen:
1. Generation, 1000 Standardcontainer, Länge: 137 bis 192 Meter, Breite: 28 Meter, Tiefgang: 10 Meter, Baujahr: ab 1960

2. Generation, 2000 Standardcontainer, Länge: 213,5 Meter, Breite: 28 Meter Tiefgang: 11,5 Meter, Baujahr: ab 1970

3. und 4. Generation, 3000 bis 5000 Standardcontainer, Länge: 260 bis 295 Meter, Breite: 32,2 Meter, Tiefgang: 12,5 bis 13,5 Meter, Baujahr: ab 1980

Post Panmas, 5000 bis 6000 Standardcontainer, Länge: 284 bis 318 Meter, Breite: 39,2 bis 42 Meter, Tiefgang 13,5 Meter Baujahr: ab 1992

5. Generation, 6000 bis 7000 Standardcontainer, Länge: 350 Meter, Breite: 42,8 Meter, Tiefgang: 14,5 Meter, Baujahr ab 1997

Fig. 1.1: Development of Container Ships

As in many cases high-level bridges in ports are unfeasible, this development has lead to a renaissance of movable bridges.

1.2 Short description of movable bridge types

1.2.1 Lift bridges

Lift bridges are suitable for big spans, but their clearance is limited by the lift-towers which – even when the bridge is closed – have a great impact onto the environment, Fig. 1.2. The cables linking the bridge and the counterweights suffer from a rather important wear.

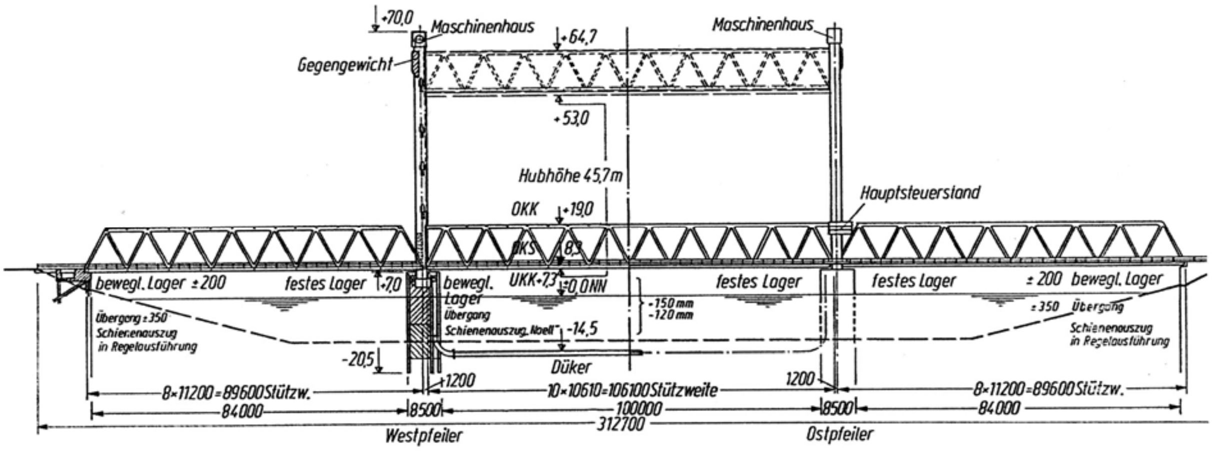


Fig. 1.2: Kattwyk Liftbridge at Hamburg

1.2.2 Swing bridges

Swing bridges are also suitable for big spans and do not limit the clearance. The biggest bridge of this type crosses the Suez-canal at El Ferdan with a free span of about 300 m, Fig. 1.3.

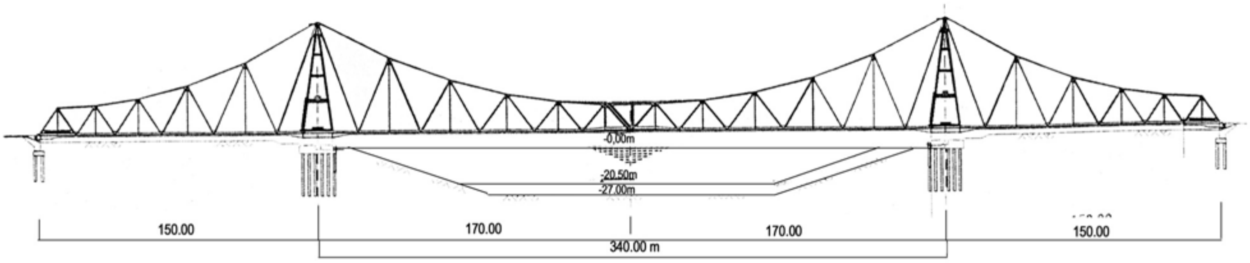


Fig. 1.3: Swing bridge across the Suez-canal at El Ferdan

Disadvantages of swing bridges are

- when opened they occupy the embankment over a length of about half their span
- for geometrical reasons it is impossible to have separated bridges for railway and highway in close vicinity.

1.2.3 Bascule bridges

Bascule bridges may have a single flap or double flaps and are also adequate for big spans without limiting the clearance. The connection between the two flaps may transmit shear forces only or shear and bending.

For rather big heights above the water the counterweight may be attached to the rear arm as a pendulum, Fig. 1.4, for reduced heights it has to be integrated to it, Fig. 1.5.

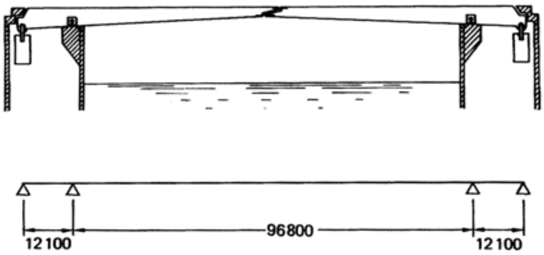


Fig. 1.4: Bascule bridge with hang on counterweight: Bridge across the bay of Cadiz

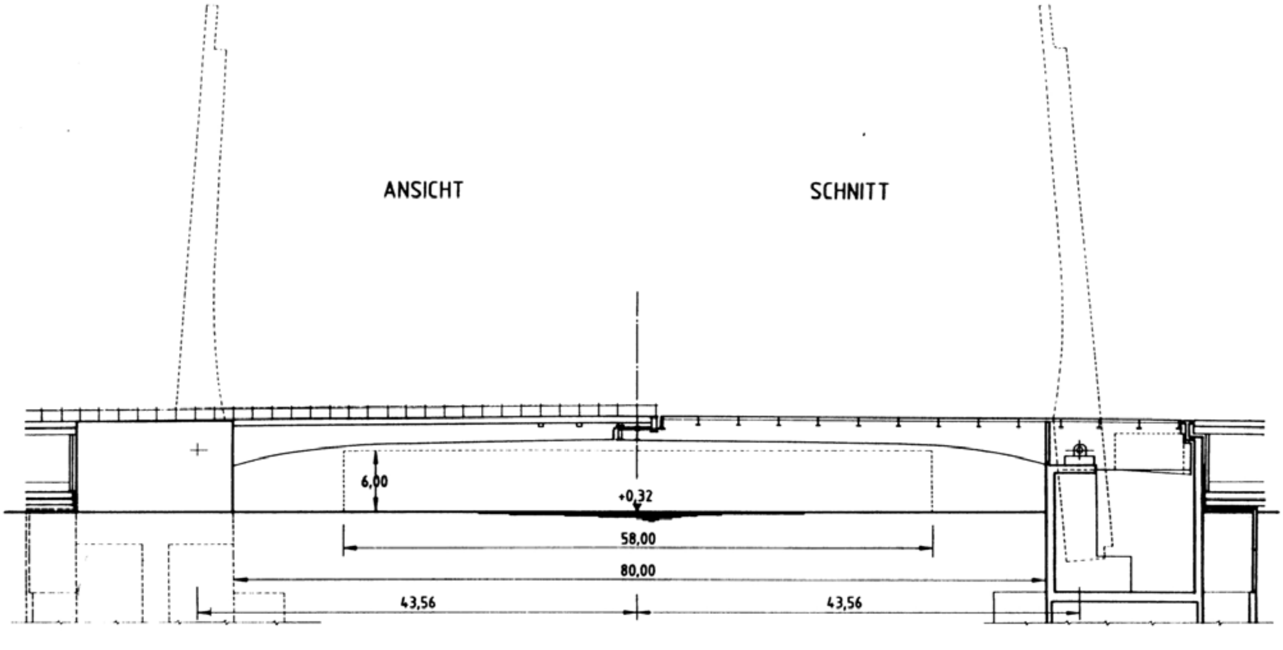


Fig. 1.5:Bascule bridge with counterweight integrated into the rear arm: Galata Bridge at Istanbul (see also point 4).

1.2.4 Balance beam bridges

Draw bridges, the precursors of bascule bridges, are most probably the oldest type of movable bridge, Fig. 1.6. Compared to bascule bridges they have

- the advantage of rather simple piers and a high architectural potential, Fig. 1.7.
- the disadvantage that they permit rather reduced spans only.

Fig. 1.6: Drawbridge at Kappeln / Netherlands

Fig. 1.7: Diffené Bridge at Mannheim

1.3 Outlook onto the paper

The paper deals with the most outstanding movable bridges designed by Leonhardt, Andrä und Partner during the last five decades: one lift bridge, three swing bridges and one bascule bridge; and with a design proposal for a double balance beam bridge.

2. Lift bridge with concrete towers: Guaiba River Bridge at Porto Allegre, Brazil (1954 – 1960) [2]

2.1 General

This bridge has a total length of 5665 m. It consists of

- a 2013 m long access bridge and a flyover, linking roads parallel to the river with the road crossing it
- the bridge across the Guaiba river properly speaking, with a total length of 777 m. Its main span, with a clear span of 50 m and a clearance of 40 m, is designed as lift bridge
- the 344 m long bridge across the Furado Grande river
- the 774 m long bridge across the Saco Alamôa bay
- the bridge across the Jacui river, with a total length of 1757 m and a main opening of 50 x 20 m.

With exception of the lift bridge, the entire bridge is from prestressed concrete, with regular spans of 43 m above water and 21,5 m over land.

2.2 The lift bridge

2.2.1 General

The lift bridge has a free span of 50 m and a clearance above the low water level of

- 13,5 m under service
- 40 m when opened,

the lifting height is, hence, 26,5 m.

It consists basically of

- the bridge deck, a steel bridge with orthotropic plate and
- the 4 rounded towers from reinforced concrete, which hoist (and hide) the concrete counterweights and the machinery.

By this design of the towers, the often ugly appearance of lift bridges is avoided, Fig. 2.1.

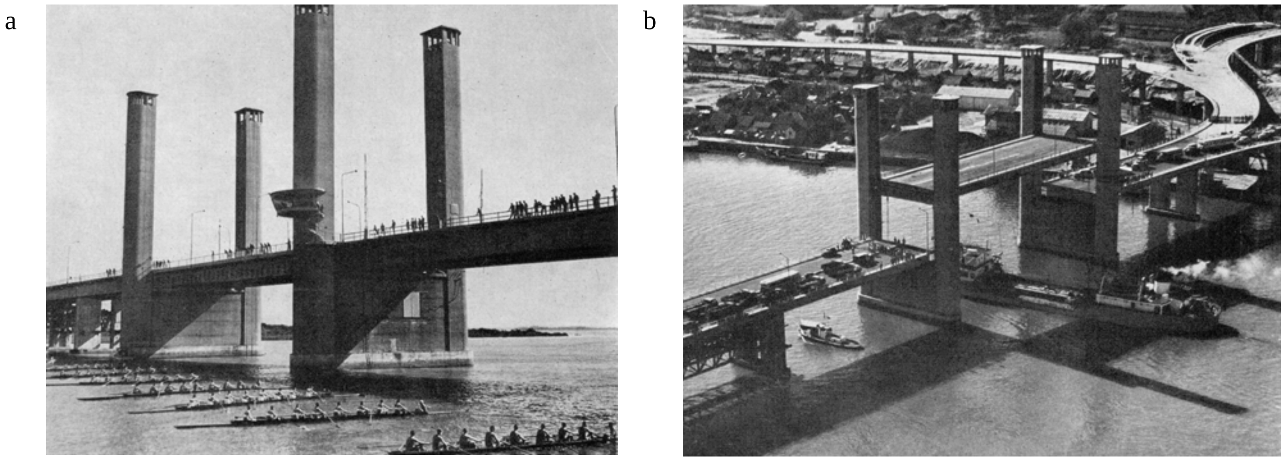


Fig. 2.1: The finished lift bridge: a) under service, b) opened to a major ship

2.2.2 Bridge deck

The bridge deck has a span of 55,8 m and

- the four lane roadway	16,00 m
- the walkways 2 x 1,15 m	2,30 m
	18,30 m

The distance of the main girders is 13 m and the 2 cantilevers are 2,65 m long, Fig. 2.2

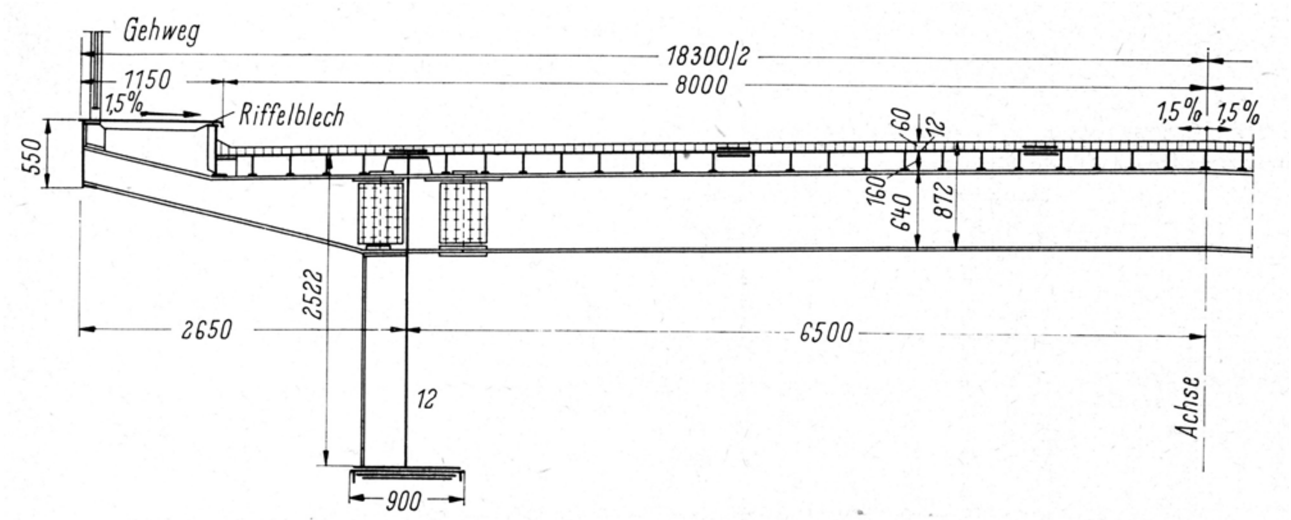


Fig. 2.2: Section of the bridge deck

The orthotropic deck consists of

- the deck plate with a thickness of 12 mm
- the bulb-shaped longitudinal ribs with a distance of 310 mm and a depth of 160 m
- the narrowly spaced (d = 1,65 m) cross-girders with a depth of 640 mm corresponding to 1/20 of their span
- the 60 mm thick asphalt layer.

The main girders have a depth – as the approach viaducts – of 2,64 m corresponding to 1/21 of their span. They are stiffened by vertical stiffeners on their outside only, and are, hence, an early application of the tension field theory.

The weight of the steel structure is 381 t corresponding to 360 kg/m², the total weight of the bridge deck is 540 t.

2.2.3 Tower and piers

The towers and piers have a total height of 48,2 m above the lowest water level. They consist of, Fig. 2.3,

- the four free-standing towers, with a distance of 51,8 m in the longitudinal and 18,6 m in the transverse direction and a height of 35 m. They have overall dimensions of 4 x 4 m and are rounded on their outer faces. Their walls parallel to the bridge axis are 300 mm thick, the other walls 250 mm.
  The towers surround the counterweight Ø 3 m x 6 m of heavy weight concrete.
- the 11,6 m high piers connecting the towers underneath the bridge deck. They have two walls with a distance of 3,0 m and a thickness of 250 mm.
- the 28,4 m x 4,9 m x 2,0 m pile caps
- a total of 66 driven piles Ø 0,52 m per pier, system Franki.

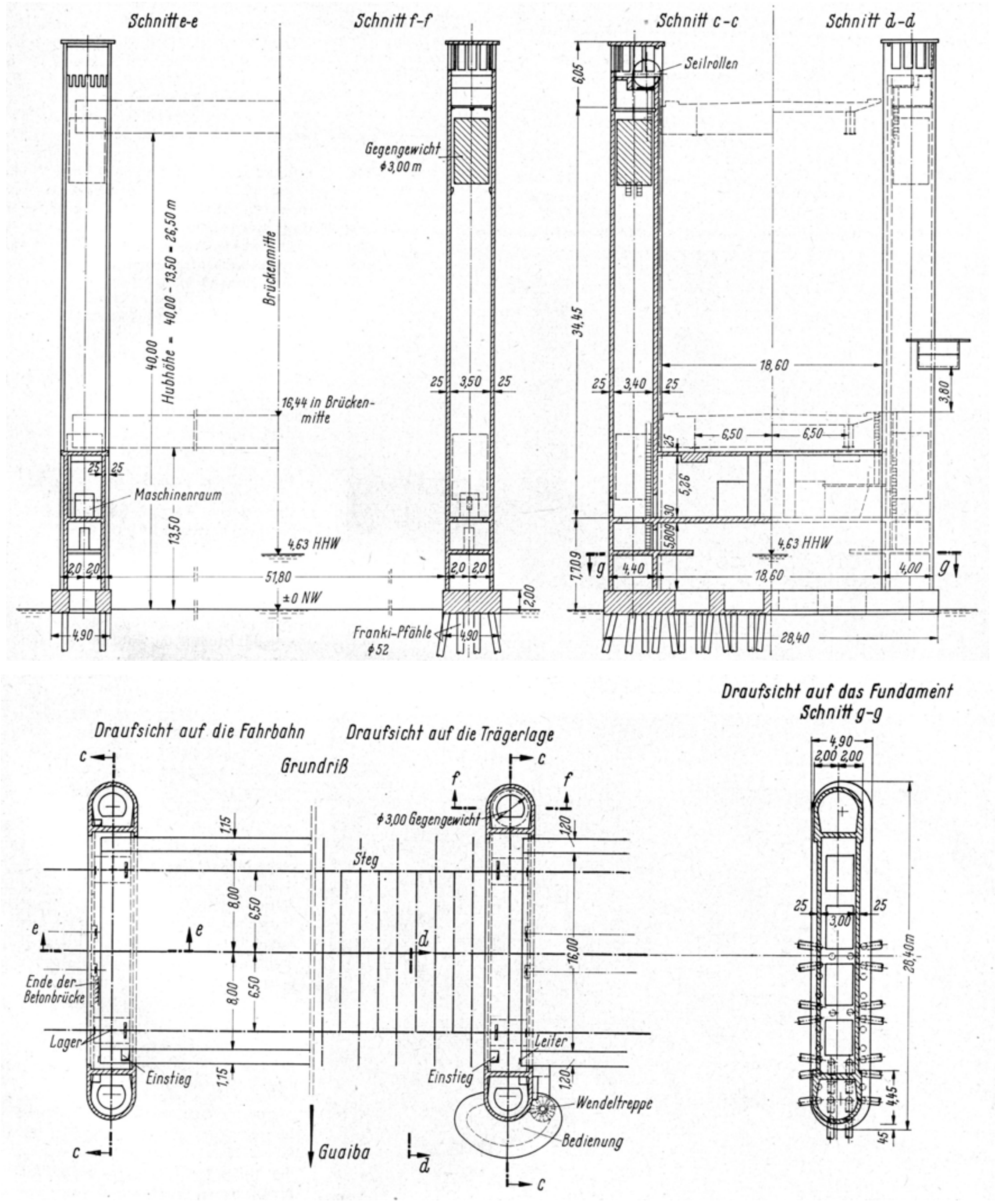


Fig. 2.3: Towers and piers

2.2.4 Mechanical installations

The wheels for turning around the cables – connecting the bridge deck and the counterweights – and the entire machinery at the top are also included into the towers. What improves the esthetical appearance of the bridge substantially.

The hoisting and lowering of the bridge deck are controlled from a cabin on the outside of one of the towers, Fig. 2.1 a.

3. Swing bridge 1: The prestressed concrete bridge across the Shatt-Al-Arab, Iraq (1972 – 1978) [3]

3.1 General

The bridge across the Shatt-Al-Arab consists of, Fig. 3.1,

- the western section, with a total length of 331,75 m
- the eastern section, with a total length of 430,15 m
- a viaduct linking the main bridge to the Sindibad island.

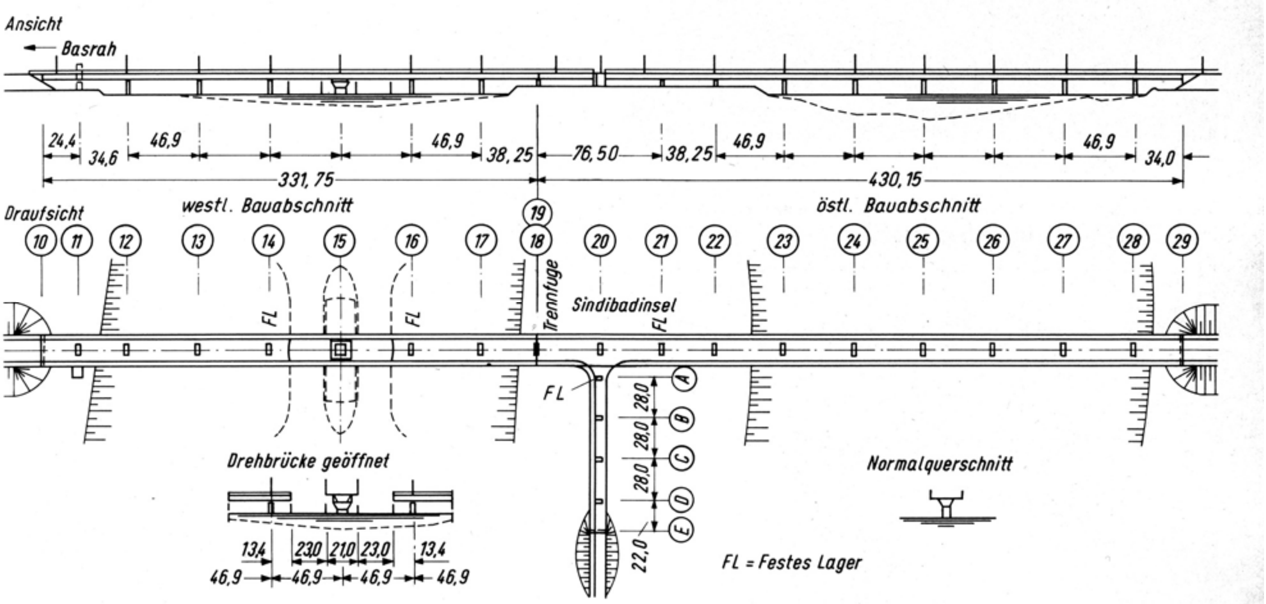


Fig. 3.1: General Layout

The centre part of the western section is a swing bridge with a total length of 67 m, giving space to two shipping channels of 23 m each.

The mainbridge has regular spans of 46,9 m and a width of 21 m; the viaduct has regular spans of 28 m and a width of 10,75 m.

The entire bridge deck – including the swing bridge – is from prestressed concrete.

The main bridge has been built by incremental launching, with a unit length of 15,63 m corresponding to 1/3 of the regular span. With respect to this construction procedure, its depth is 3,65 m corresponding to 1/12,8 of the regular span.

3.2 The swing bridge

3.2.1 Bridge deck

swing bridge has two cantilevers of 33,5 m each, Fig. 3.2 a.

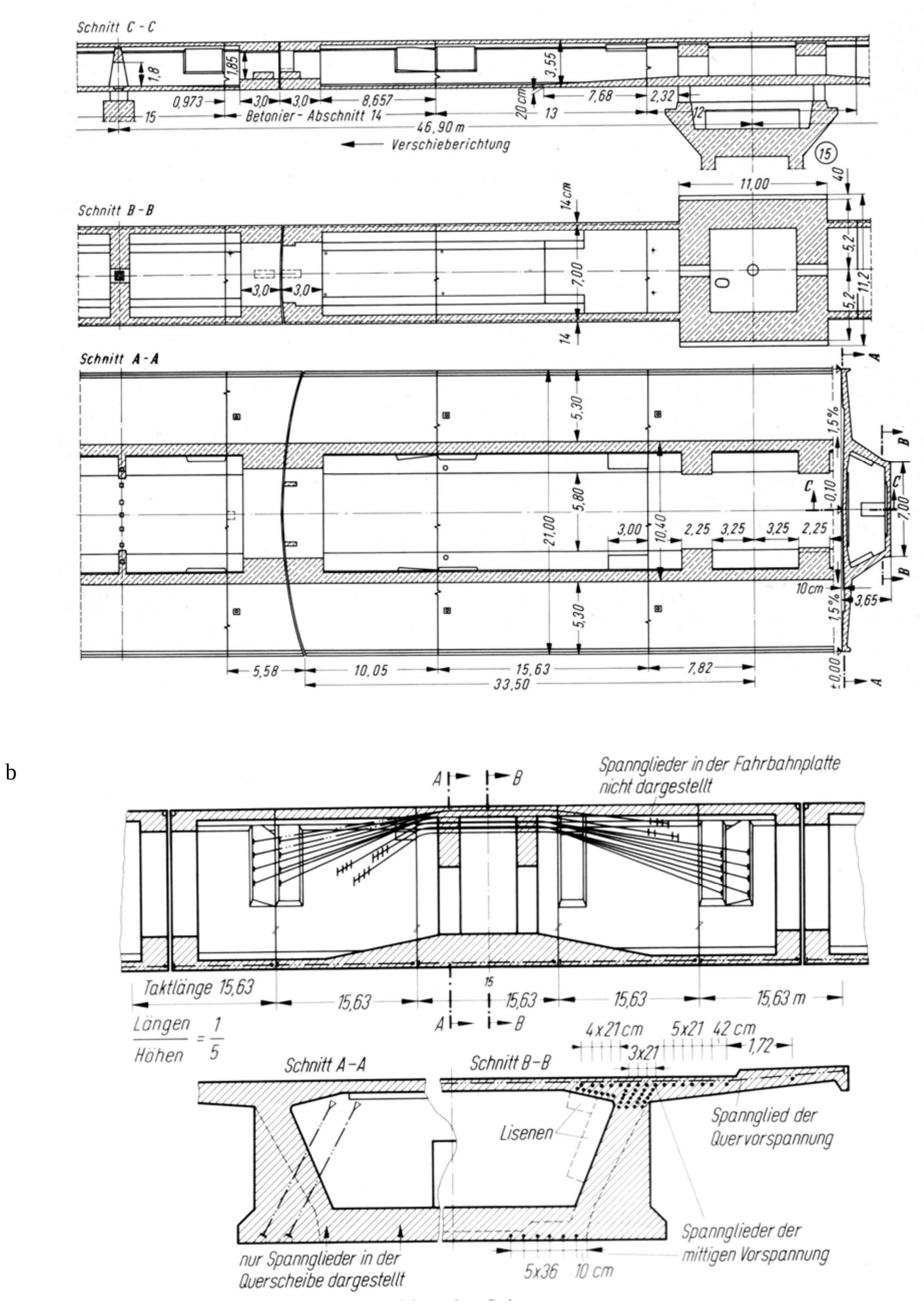


Fig. 3.2: Swing bridge: a) Layout, b) Prestressing

The cross-section consists of

- a trapezoidal box girder with a width of 7 m at its bottom and 10,5 m at the top
- two 5,25 m wide cantilevers.

The bridge deck is prestressed in the longitudinal as well as in the transverse direction, Fig. 3.2b. For the launching, continuity tendons were introduced at both bridge ends which were cut after the bridge had reached its final position.

3.2.2 Main pier

The main pier consists, Fig. 3.3a, of

- the massive pier table square 12,8 m
- the hollow shaft square 6,5 m, with a wall thickness of 1,0 m
- the 2,0 m thick pile cap
- 16 drilled piles Ø 2 m with a length of about 40 m.

The pier table is heavily prestressed, Fig. 3.3b.

The bridge deck rests at the pier on a turning circle with a radius of 10 m, Fig. 3.3c.

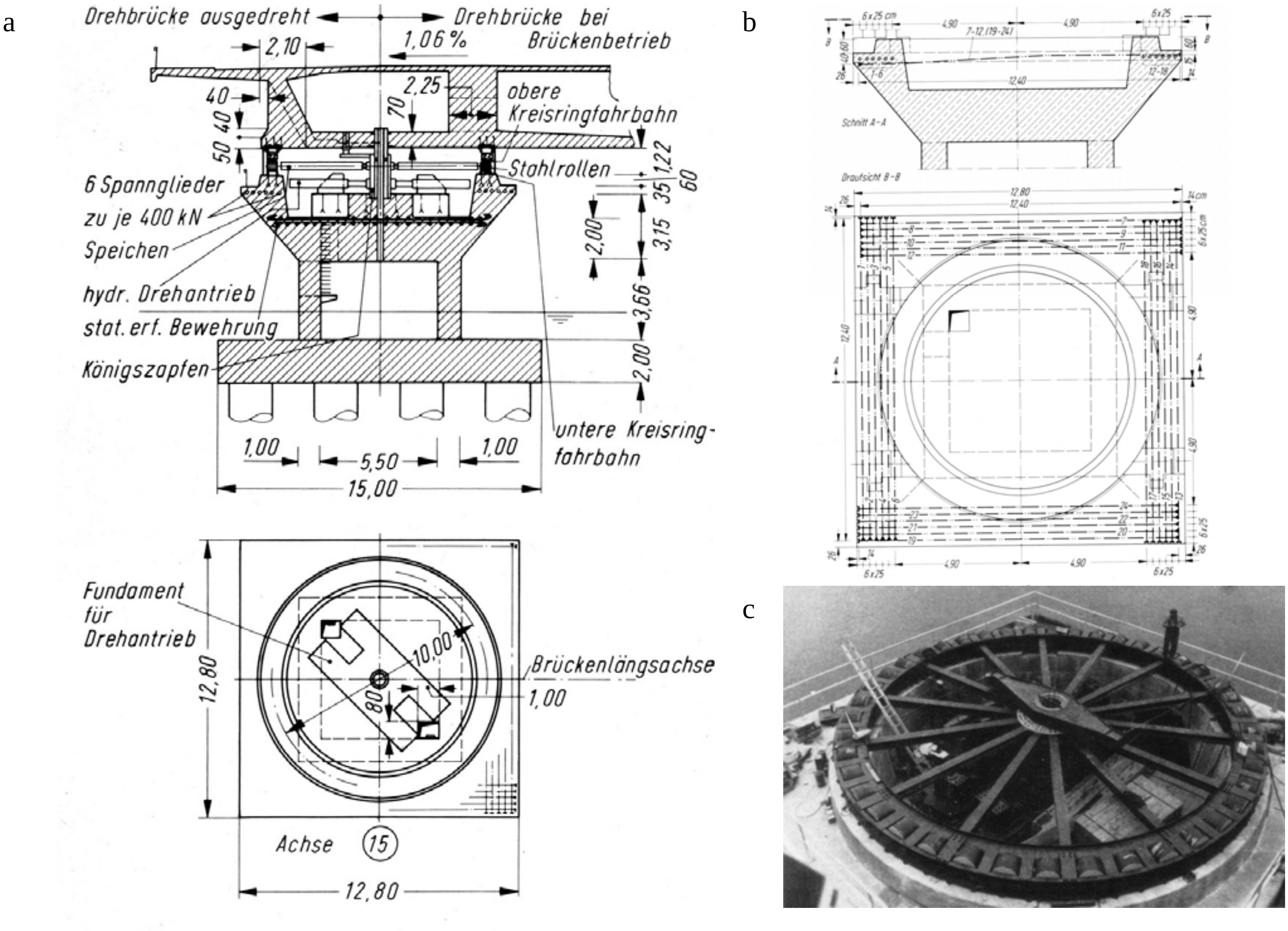


Fig. 3.3:Main pier: Layout, b)Prestressing of the pier table, c) Turning circle

3.2.3 Joint to the fixed part

The swing bridge is locked to the fixed part by locking devices which can be retracted in order to facilitate the opening of the bridge, Fig. 3.4a.

The circular expansion joint is open, with a gap of 30 mm, Fig. 3.4b.

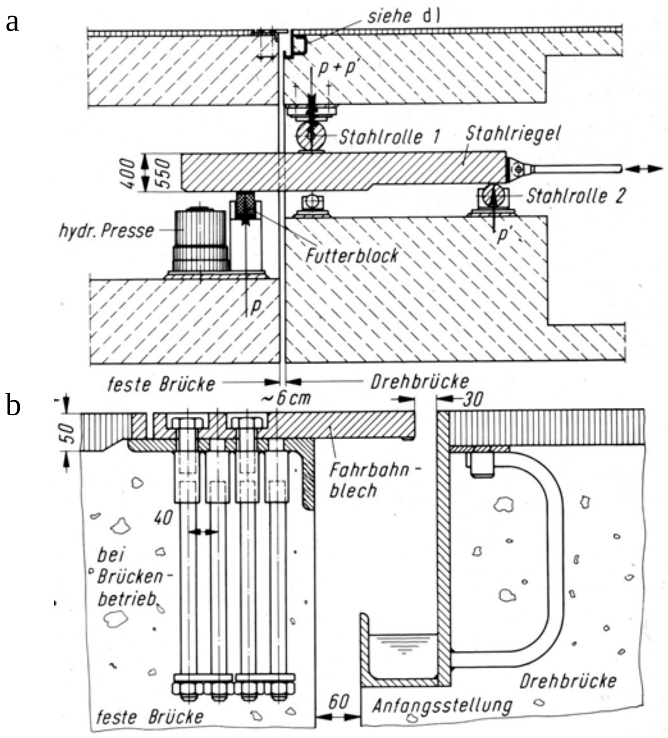


Fig. 3.4: Joint to the fixed part: a) Locking device, b) expansion joint

4. Swing bridge 2: Cable-Stayed Bridge in the Port of Barcelona, Spain (1997) [4]

4.1 Introduction

This bridge was the first of quite a number of movable bridges built during the last decade in the ports of Spain with the aim of adapting these ports to the needs of modern ship traffic.

The tender design asked for a double flap bascule bridge with a free span of 85 m, Fig. 4.1. This span is small for the design ship – 20.000 dwt, L = 250 m, W = 35 m, sailing at 2,2 m/s – but left the main piers – founded on piles – in the water and, hence, exposed to ship impact.

Leonhardt, Andrä und Partner GmbH, Stuttgart, prepared for a JV of Spanish contractors an alternative design as swing bridge. The main aim of this design was to avoid the expensive piers in the water and thereby increase the safety of navigation.

Unfortunately, this alternative was not selected for construction. Nevertheless, for ease of grammar we use the verb forms corresponding to a built bridge.

4.2 Description of the design

4.2.1 Main structural system

The main structure of the swing bridge is a cable-stayed bridge with spans of 180 m and 75 m and a single tower with 4 legs, Fig. 4.2. The effective span lengths are reduced by cantilevers of the approach viaducts to 159 m and 68 m respectively. In order to have the permanent loads centralized with respect to the axis of the towers, the steel composite deck of the main span is counteracted by a concrete side span.

In the longitudinal direction, the cables are anchored in regular intervals of 17 m, in the transverse direction at both borders of the deck.

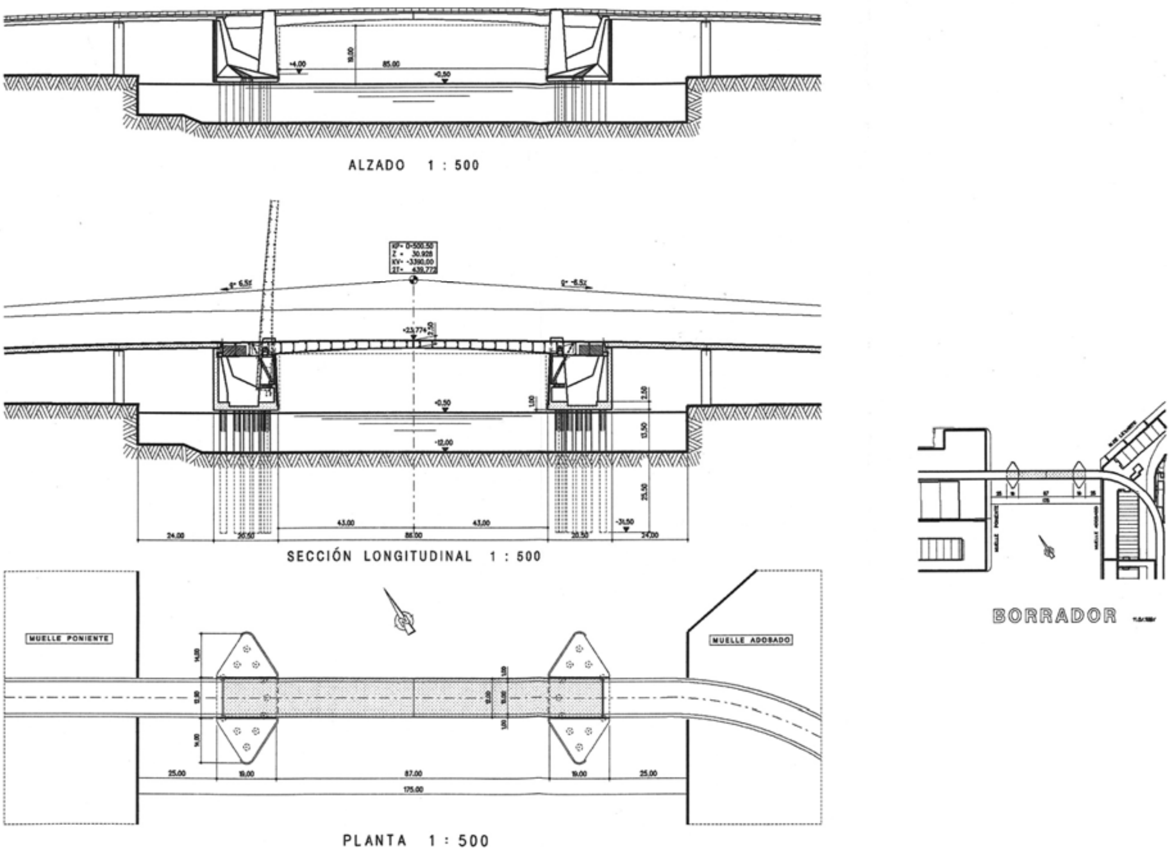


Fig. 4.1: Tender Design

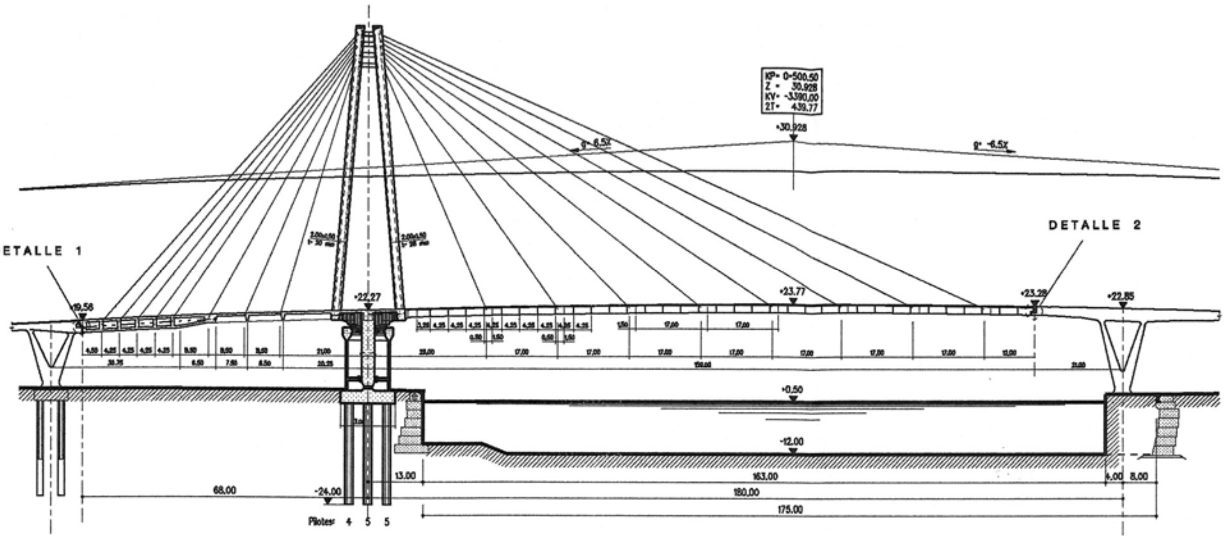


Fig. 4.2: Layout of the Alternative

4.2.2 Bridge deck

a) Traffic and total width

The bridge deck consists of

-	the two lane roadway	10,00 m
-	the walkways and cable anchorage zone 2 x 2,25	4,50 m
		14,5 m

b) Main span

The steel composite bridge deck is built up from, Fig. 4.3a,

- the 2,3 m deep main girders with a distance of 12,3 m
- the 2,10 m deep cross girders spaced at 4,25 m
- the 225 mm thick roadway slab with an 80 mm thick asphalt layer; in the walkway and cable anchorage zone, the slab thickness is 500 mm.
- the concrete cable anchorages at the outside of the main girders.

c) Side span, close to the pier

The bridge deck from prestressed concrete is a plate-beam structure with a depth of 2,3 m, Fig. 4.3b.

It consists of

- the main girders with an outer distance of 12,3 m and a width of 1,75 m to 2,0 m.
- the cross girders with a spacing of 8,5 m
- the 600 mm thick slab.

d) Side span, counterweight zone

In this area the bridge deck is a box girder with outer dimensions of 12,3 m x ~3,2 m, Fig. 4.3c. The box is filled with heavy weight concrete in order to counteract the long main span.

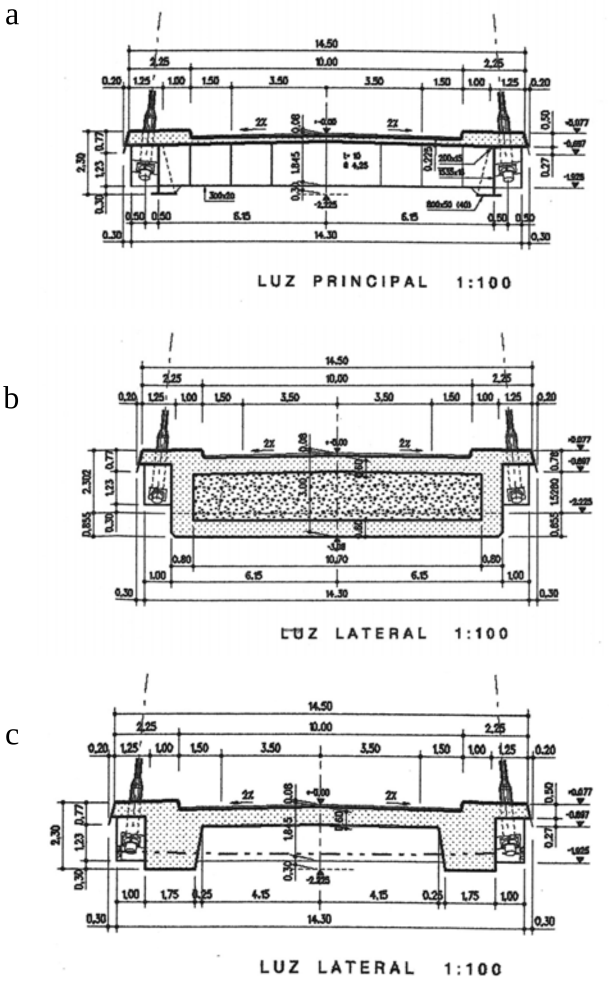


Fig. 4.3: Cross-sections of bridge deck

4.2.3 Tower and pier, Fig. 4.4

a) Towers

The steel towers have a height of 67,7 m above the bridge deck. They consist of 4 legs with outer dimensions of 1,5 m x 2 m, and are stiffened by 4 cross girders at their top.

The towers are supported by a solid part of the bridge deck which is prestressed in the longitudinal as well as the transverse direction.

b) Pier

The circular pier has an outer diameter of 11,2 m, and a wall thickness of 400 mm, which is thickened to 2 m at the top where it hoists the turning table with a diameter of 10,8 m.

The pier is founded on fourteen 24 m long drilled piles Ø 2 m and a 3 m thick pile cap.

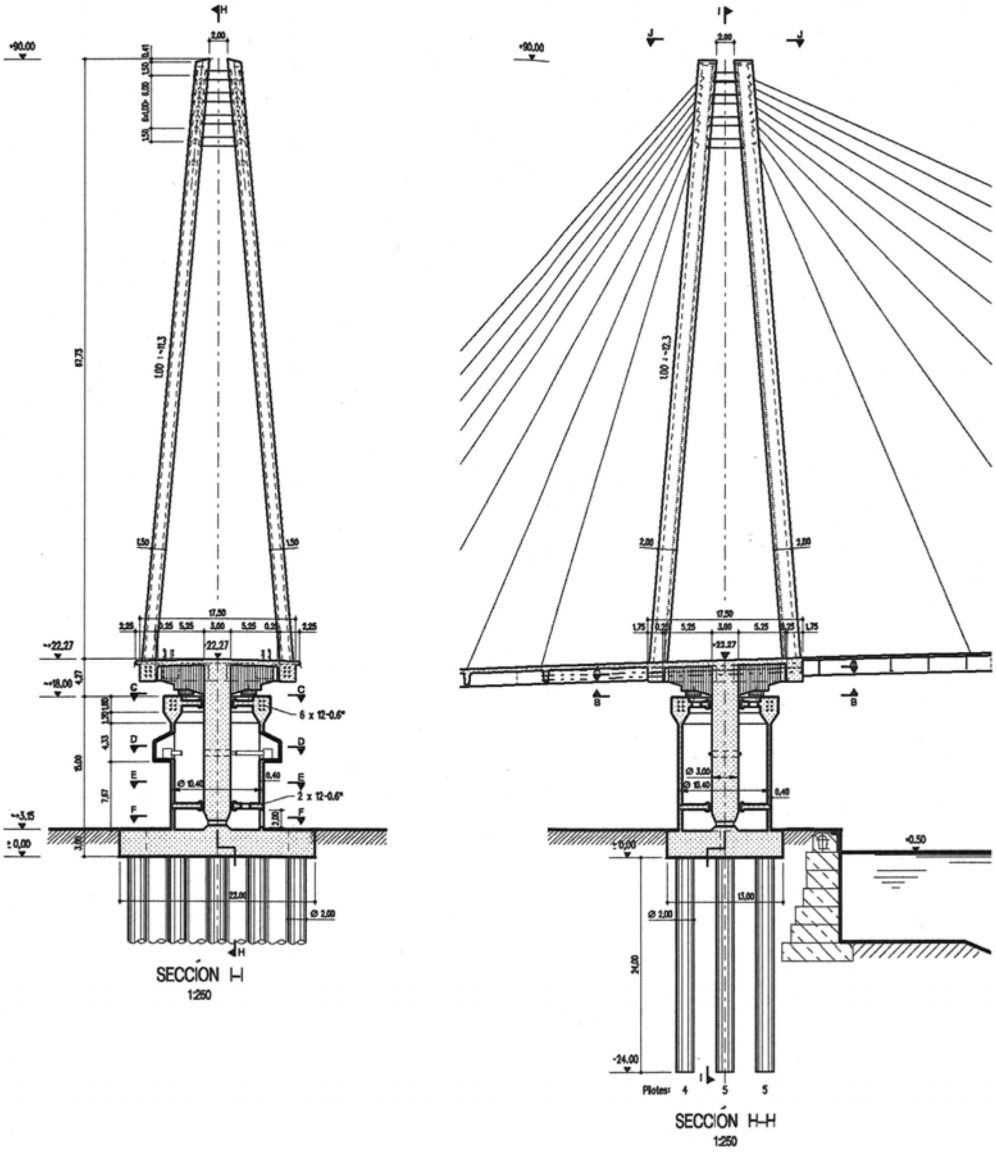


Fig. 4.4: Towers and piers

4.2.4 Mechanical equipment

The bridge deck is moved by a vertical axis of 3 m which takes horizontal forces only and which can be turned by two hydraulic cylinders, Fig. 4.5.

4.3 Construction

The bridge was assembled parallel to the embankment and later turned into its service position.

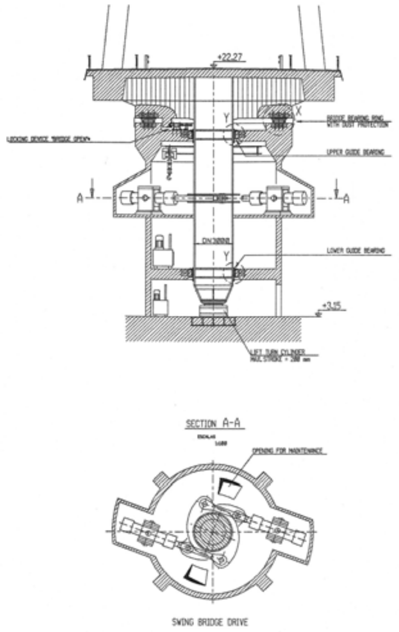


Fig. 4.5: Mechanical equipment

5. Swing bridge 3: The railroad bridge across the Sungai Prai River Bridge, Malaysia (2008 -) [5]

5.1 Introduction

A double track electrified railway line between Padang Besan and Ipoh crosses the Sungai Prai River from West to East with two spans of 45 m. For a contractor responsible for the construction of the complete rail link, LAP prepared concept and tender design services including the mechanical and electrical elements.

5.2 Description of the design

The main structure consists of 2 balanced spans composed of a steel grid supporting the concrete slab and two steel sails at the edge as main load carrying members. The deck width is 11 m resulting together with the steel sails of 1 m each in 13 m overall width, Fig. 5.

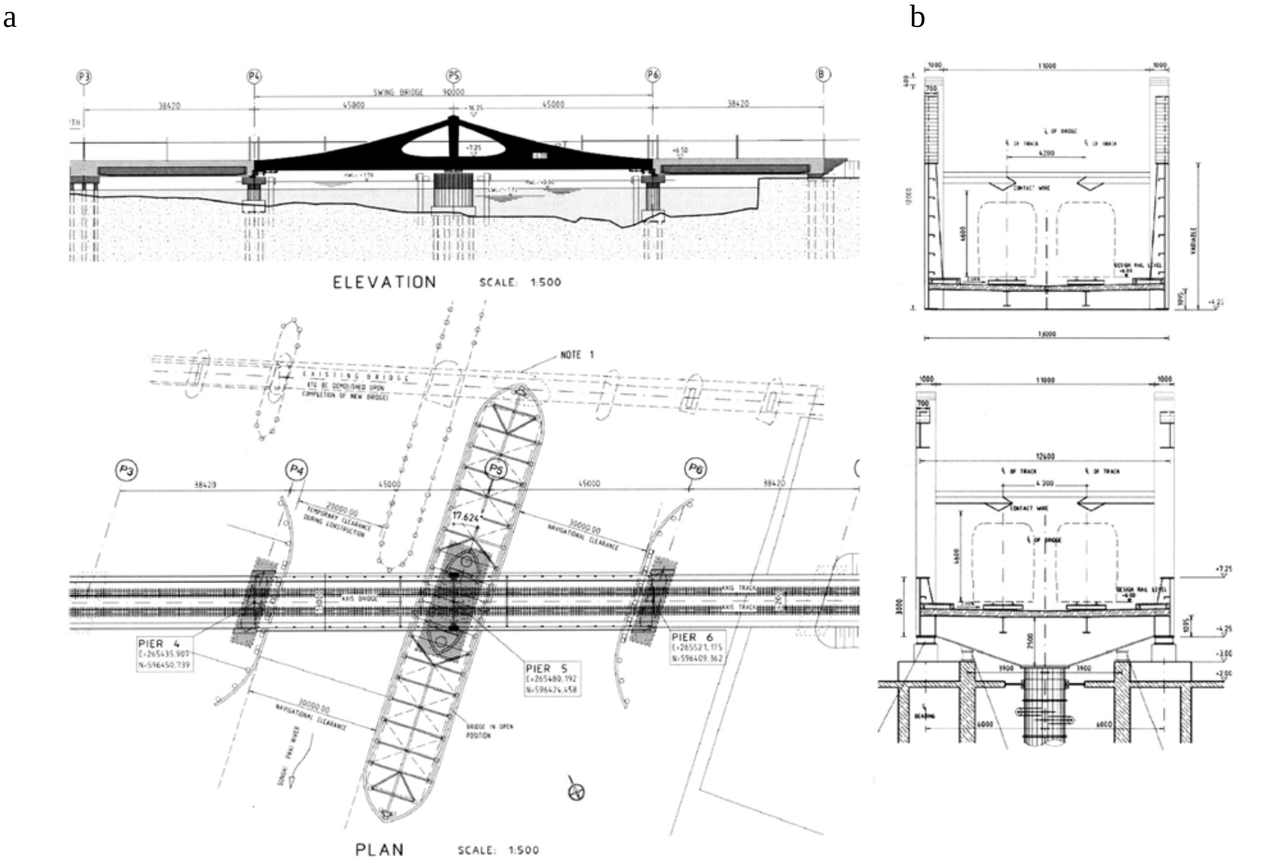


Fig. 5 a) Layout, b) Sections

Cross beams of 1,40 m depth at 4 m distance carry the traffic loads to the main girders.

The main girders consist of a plate girder of variable depth between 2 and 12 m, a V-shaped strut in the axis of the central pier and two openings in the web of the plate girder. All stiffeners of the plate girders are located at the inner side, providing a smooth outside face of the structure.

Supply of electricity for the railway can be held independent from the structure with typical posts and contact wire supports as throughout the railway link.

Below the centre pier all turning equipment and rotational bearings are located in a hollow pier partially below water.

The centre pivot shaft will provide vertical and horizontal support during the swinging operation.

A hydraulic lift / turn cylinder allows to transmit the torque for slewing and to lower the structure on bearings for the railway service situation. The pivot shaft is free from loads under service condition.

In the service position the bridge is locked with wedge-shaped end-locks and a rail locking device is engaged to provide continuity with the rail.

In the open position parallel to the river the bridge is protected by a system of guidance steel structure which keeps the footprint of the bridge in open position free from navigation.

6. Double flap bascule bridge: The New Galata Bridge at Istanbul, Turkey (1985 – 1993) [6]

6.1 Introduction

The New Galata Bridge across the Golden Horn links the quarters of Eminönü and Karaköy directly on site of the former steel floating bridge built in 1912.

The 477,45 m long and 42 m wide bridge, Fig. 6.1 and 6.2, consist basically of the

- centre bascule bridge with a clearance of 80 m and the corresponding bascule bridge piers,
- double deck approach bridges with 8 spans of 22,3 m each, with the road and light railway traffic on the upper deck and shops, restaurants and the like on the lower deck,
- abutments.

In between these 2 x 3 elements and between the bascule bridge piers and their piles, buffer bearings are provided.

Due to a water depth of up to 40 m and poor soil of another 40 m, the bridge is founded on driven or drilled hollow steel piles, with a diameter of 2 m, a wall-thickness of 20 mm and cathodic corrosion protection.

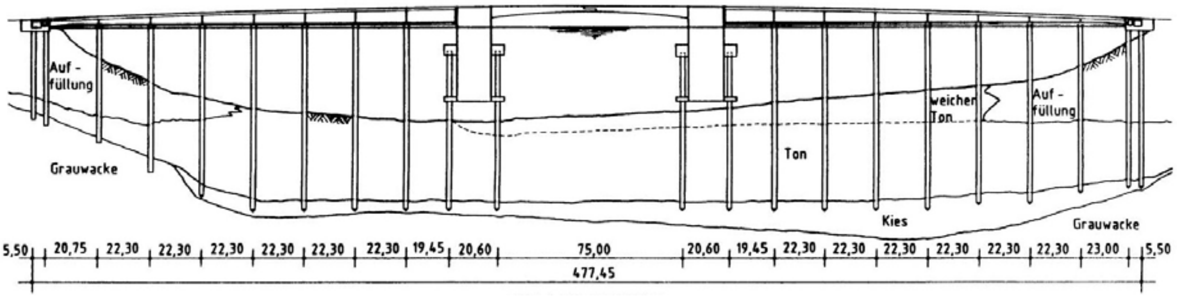


Fig. 6.1 General Layout

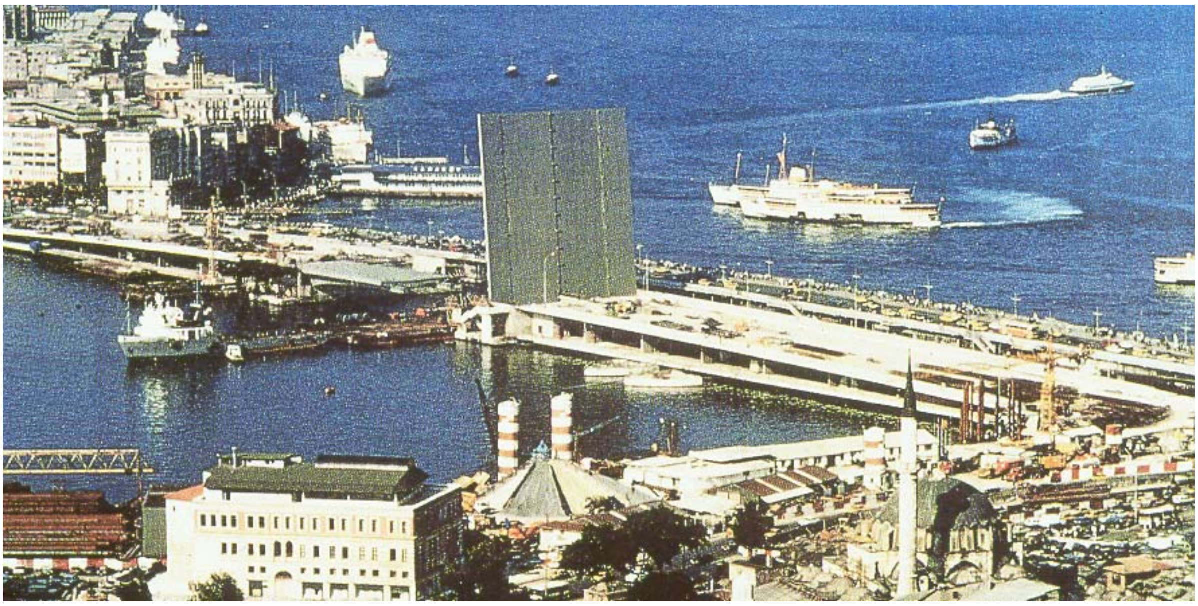


Fig. 6.2 The Finished Bridge

6.2 Design

6.2.1 Bascule Bridge

The free span of 80 m and a total width of 42 m render the bascule bridge the world’s largest, Fig. 6.3 and 6.4. The total length of the flaps, 54,5 m each, is divided by the axis of rotation into 2 cantilevers of 42,8 m and 11,7 m.

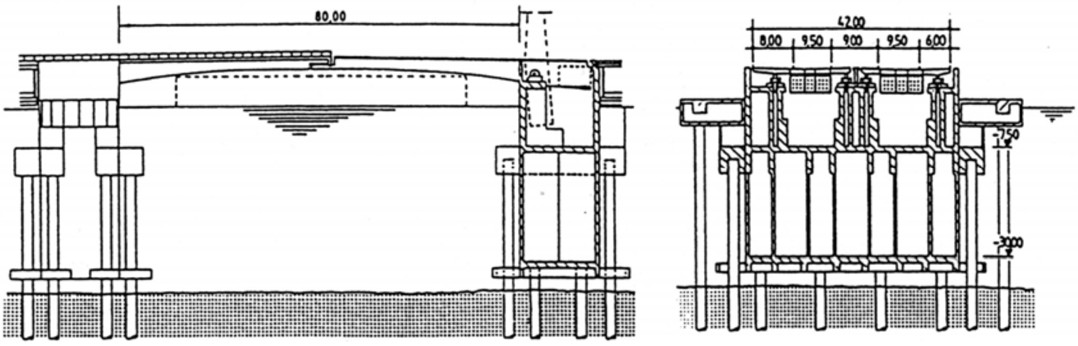


Fig. 6.3 Bascule Bridge, General Arrangement

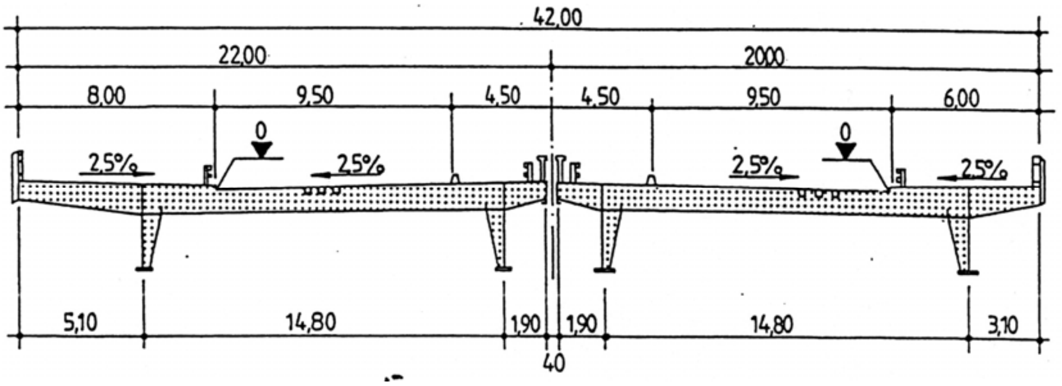


Fig. 6.4 Bascule Bridge, Cross-Section

In the design of the bascule bridge piers, two contradictory requirements had to be fulfilled: For the absorption of ship impact they had to be stiff and for that of earthquake flexible.

This could be achieved by a pier going down to the seabed and founded on 12 piles, which are fixed to the pier between -13 m and -7,5 m and elastically supported at -32 m, Fig. 6.5. In order to avoid an overloading of the piles – or additional piles – the piers are made hollow. In spite of being exposed to a water pressure of up to 35 tons/m², the pier walls are not waterproofed, but are reinforced for a crack width of w_{95} = 0,2 mm.

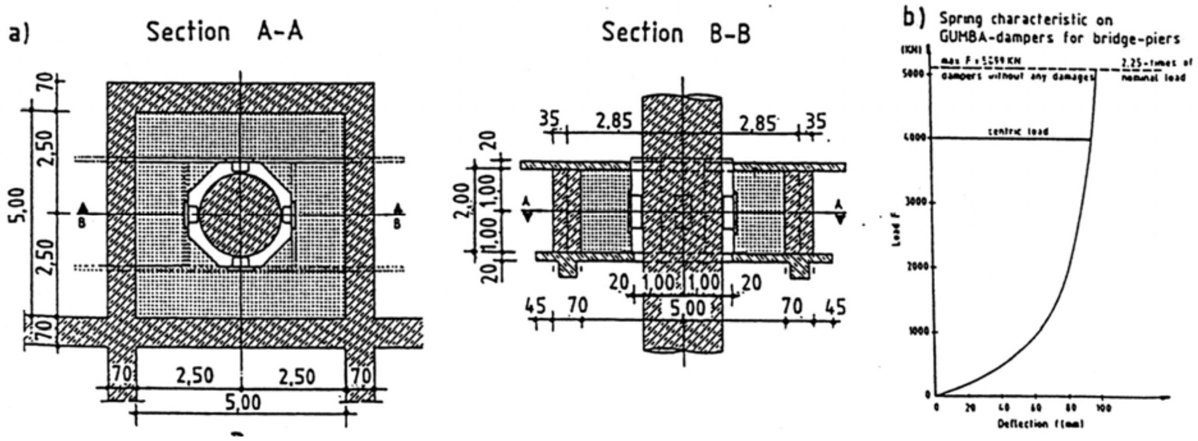


Fig. 6.5 Bearings at -32 m; a) Layout, b) Load-Displacement Diagram

6.2.2 Approach Bridges

a) Structural Design

Both decks of the approach bridges are 4-fold T-beams with a constant depth of about 1,2 m and a width of 3 m, enlarged to 4 m at the piers, Fig. 6.6. The prestressing consists of 4 Ø 0,6" St 1570/1770 transversely and 9 tendons, of 15 Ø 0,6" St 1570/1770 each, per beam longitudinally.

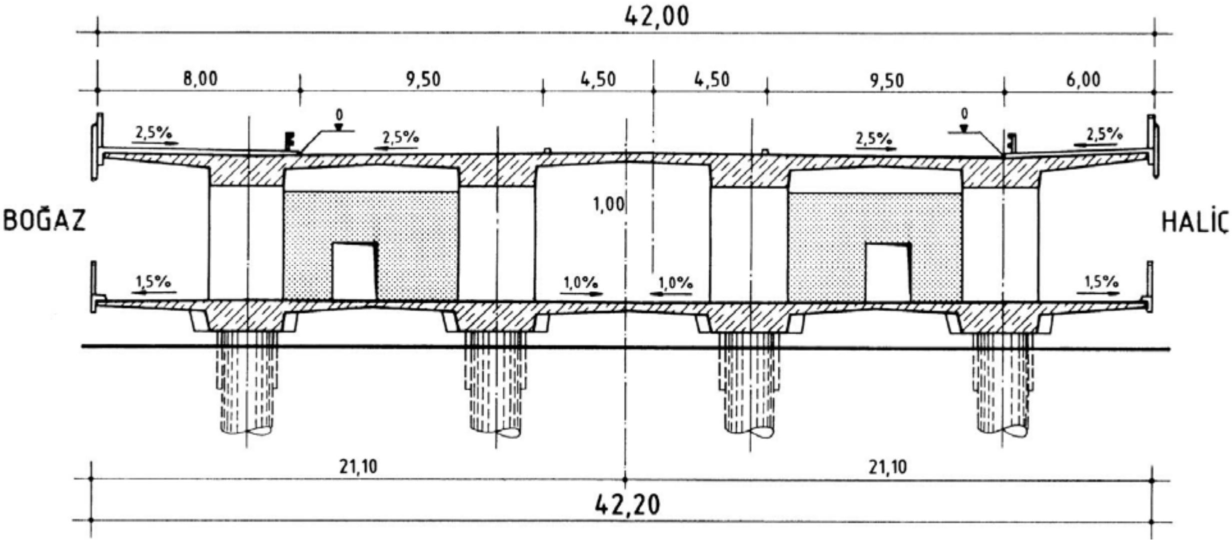


Fig. 6.6 Approach Bridge

b) Bearings

Bearings for vertical loads are, due to the longitudinal elasticity of the piles, needed at the bridge ends only. In order to keep them out of the splash water zone, they support the upper deck only so that the end walls are tension walls. The displacement of these bearings has been sized generously in order to avoid a dripping down of the end spans in case of an unforeseen strong longitudinal earthquake.

Bearing for lateral forces are again at the abutment only; they are designed as Teflon sliding bearings.

Longitudinal forces are absorbed at both ends of the approach bridges by buffer bearings, which are working under compression only. In order to avoid bending of the walls, these bearings are at both deck levels. The consist of rubber discs and have pronounced hysteresis, Fig. 6.7.

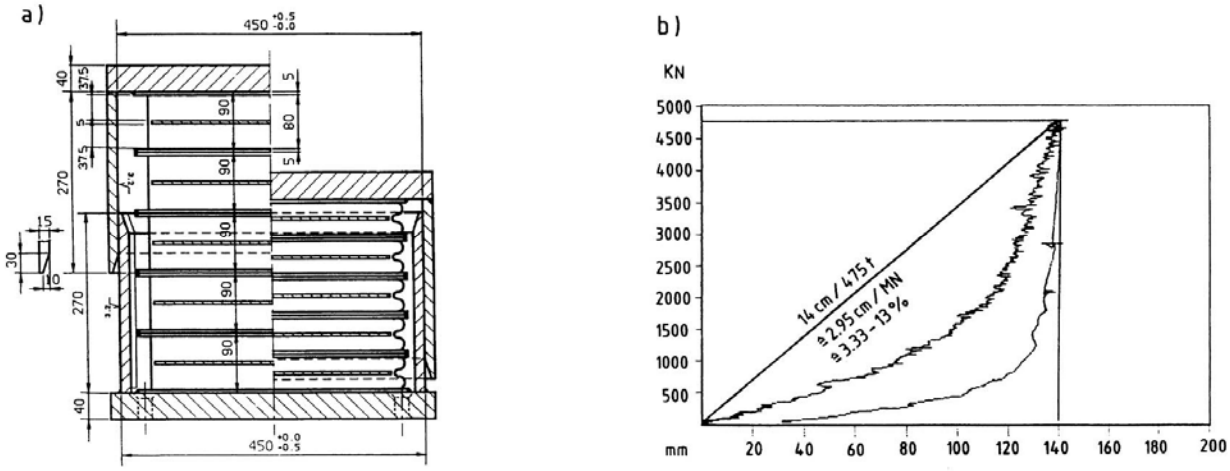


Fig. 6.7 Longitudinal Buffer Bearings: a) Design, b) Load Displacement Diagram

6.2.3 Piles

a) Approach Bridges and Abutments

In order to reduce the masses involved into an earthquake and to save costs, the pile shafts are designed as hollow steel pipes, with an outer diameter of 2 m and a wall thickness of 20 mm only, steel quality St 52-3.

b) Bascule Bridge Pier

The piles of the bascule bridge pier are filled with tremie concrete B 35 and reinforced in their upper part. The design of these piles as composite columns proved that shear connectors were needed at both ends only.

6.3 Special aspects of dimensioning

6.3.1 Ship Impact

The bridge had to be designed for the head on impact of a 8000 dwt ship sailing at 2,5 m/s. The corresponding impact force is according to the "Nordic Road Council Regulations for Ship Impact"

$$P_{[kN]} = 500 \cdot \sqrt{dwt} = 500 \cdot \sqrt{8000} \cdot 1{,}05 = 40.000\ kN$$

As a consequence of an eventual ship impact, the loss of buoyancy of the upper or lower part of the pier due to breaching had also to be considered. As the bascule bridge could, of course, not be designed against ship impact, two worst case scenarios were investigated, Fig. 6.8:

- formation of a hinge in front of the pier,
- loss of a flap between this hinge and the centre.

These scenarios did not lead to a loss of the other flap or the rear arm with the counterweight respectively.

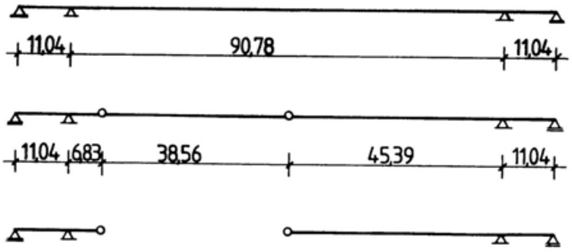


Fig. 6.8 Worst Case Scenarios

6.3.2 Earthquake Analysis

a) General

For the check of the safety under earthquakes, two methods were used. In a first step, a response-spectrum analysis was performed, assuming that the 2 x 3 = 6 elements of the bridge are completely independent in the longitudinal direction. In order to determine the displacements of bearings and jointings and the forces acting on the buffers, a time-history analysis was performed in a second step.

b) Response-Spectrum Analysis

ba) Investigated systems

The response-spectrum analysis was performed for closed flaps, opened flaps and for construction stages.

bb) Response-Spectrum and Response Modification Factors

The response-spectrum analysis was performed with the spectrum given in the tender documents and with the spectrum according to AASHTO earthquake code which yields substantially higher accelerations for the governing, rather low frequencies, Fig. 6.9. The response-modification factor was assumed as 1,0 for the spectrum according to the tender documents and 3,0 for that according to AASHTO.

bc) Safety factors

Under the spectrum according to the tender documents, the bridge behaves completely elastic, that means that the safety against yield is 1,0 at the maximum stressed point of the maximum stressed pile.

c) Time-History Analysis

ca) Distribution of the ground acceleration along the bridge

The velocity of the surface-(Love-)waves may be assumed as 3 km/s, whereas the governing eigenfrequency of the bridge is in the range of 0,25 per second. An earthquake, hence, moves along the bridge in 470/3000 = 0,15 s, what is substantially less than the period of eigen-vibration t = 1/02,5 = 4 s. Therefore, it was assumed, that the bridge is accelerated uniformly on its entire length, that means no phase difference was considered.

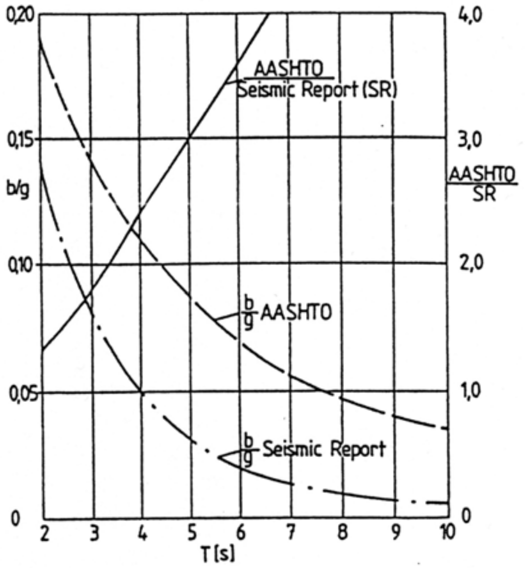


Fig. 6.9: Peak acceleration versus natural frequency

cb) Acceleration diagrams

For the time-history analysis, 6 acceleration diagrams have been generated which are compatible with the energy content of the response spectrum, Fig. 5.10a.

cc) Investigated systems

Corresponding to the progress of design and especially of the buffers, different connections between the main elements of the bridge were assumed, e.g. elastic springs, springs with a gap for the displacements under service conditions, friction, assumed and real hysteresis of the buffers, Fig. 5.10b.

cd) Results

The results were given graphically. As an example, the displacements between the abutment and the approach bridge and the reactions of the corresponding buffers are given in Fig. 5.10c and d.

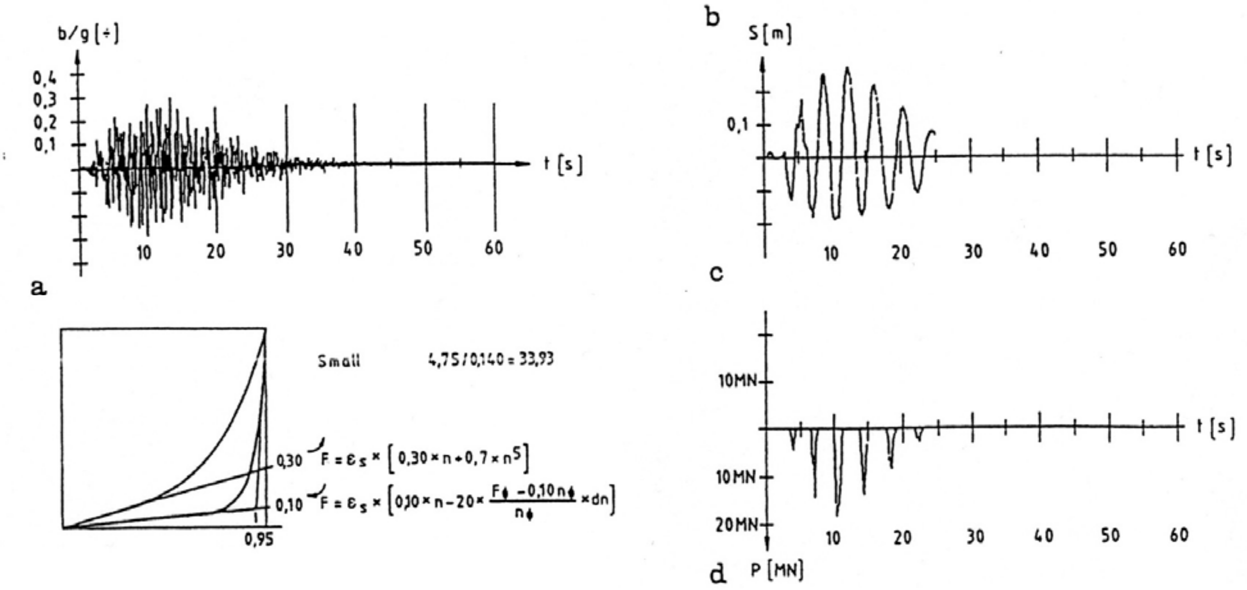


Fig. 5.10: Time-History Analysis: a) Acceleration diagram, b) Analytical description of buffers, c) Deformation of buffer 1, approx. symmetric, d) forces in buffer 1, pronouncedly non-symmetric upwards friction only, downwards friction + buffer force.

The design was prepared by a Joint Venture of Leonhardt, Andrä und Partner GmbH, Stuttgart, Germany, and Temel Mühendislik, Istanbul, Turkey. Main contractor was a Joint Venture of STFA, Istanbul, and Thyssen Engineering GmbH, Essen, Germany.

7. Double balance beam bridge - Design Proposal (2007) [7]

7.1 Design concept

So far, balance beam bridges have been built as single span bridges. Due to the articulation of the balance beam, this system takes the permanent loads only. In double balance beam bridges, the joint at the centre would have the transmit under live loads the bending moment of a single span beam.

If, instead, the rotation of the balance beam is blocked by a second bearing, the staying system participates also in taking the live loads. This allows to build balance beam bridges with two flaps and thereby double their span range. This solution is advantageous in areas where the piers of a bascule bridge have to be built in water / groundwater.

In more detail we make use of the fact that for cinematic reasons the balance beam has to have an eccentricity towards land. with an additional bearing with eccentricity towards water – which can take compression only and is automatically activated when lowering the flaps, Fig. 7.1 – the live loads can also be taken by the balance beam and the pylon and thereby the moments of the bridge deck – especially at the centre – are substantially reduced.

7.2 Comparison of section forces

7.2.1 System and loads

The free span is 80 m and the bridge width 12 m.

The permanent load – including surfacing etc. – is 5 kN/m^2 and the equivalent live load also 5 kN/m^2. Live load over the full main span is considered only.

7.2.2 Double balance beam bridge (DBBB)

The static system is

- for permanent loads a span and a cantilever of 22 m each
- for live loads a continuous beam with spans of 22 – 44 – 22 m and elastic, intermediate supports.

The tensile rod is inclined by 1:3, and the distance of the counterweight from the axis of rotation is 80 % of that of the rod.

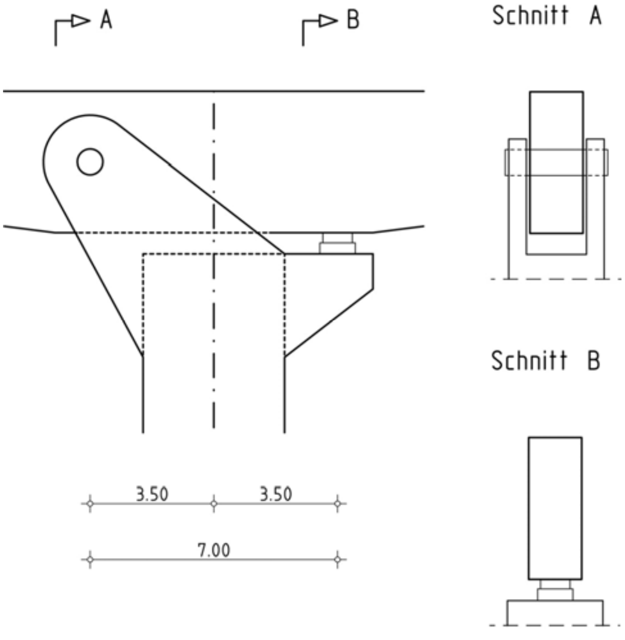


Fig. 7.1: Bearing at the top of tower

The stiffness of the balance beam and the tower are the five-fold of that of the bridge deck.

The governing bending moments and reaction forces are given in Fig. 7.2.

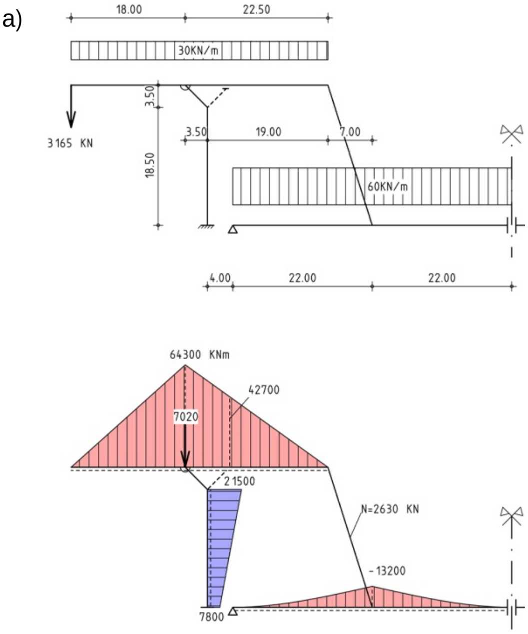
7.2.3 Double bascule bridge (DBB)

The static system is

- for permanent loads a span and a cantilever of 11 m and 45 m respectively
- for live loads a continuous beam with span of 11 – 90 – 11 m.

The stiffness at the axis of rotation is the fivefold of that at the centre.

The governing bending moments and reaction forces are given in Fig. 7.3



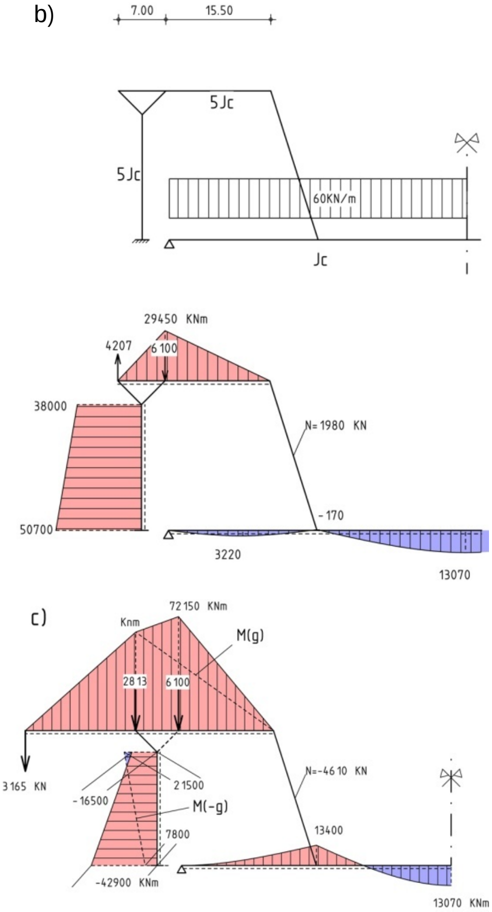


Fig. 7.2: Section forces of a double balance beam bridge: a) permanent loads, b) traffic, c) permanent loads + traffic

7.2.4 Comparison of DBBB and DBB

s. Fig. 7.2 c and 7.3 c

1. The maximum bending moment of the bridge deck of the DBBB is about 15 % of that of the DBB only.
   This allows to reduce the construction depth and to lower the gradient.
2. At the centre joint, the live load moments of both bridge types are virtually the same.
3. The counterweight of the DBBB (3165 kN9 corresponds – due to the longer lever arm – to 45 % of that of the DBB (7.140 kN) only.
4. The reaction force of the rotation bearing of the DBBB (6.900 kN) corresponds to 40 % of that of the DBB (17.450 kN) only.
5. The governing moments of the balance beam (72.100 kNm) and the pylon (43.000 kNm) of the DBBB corresponds to 70 % and 40 % of the maximum moment of the DBB (107.600 kNm).
6. The bending moments acting onto the foundation of the DBBB (42.940 kNm) and the DBB (46.850 kNm) are basically the same.

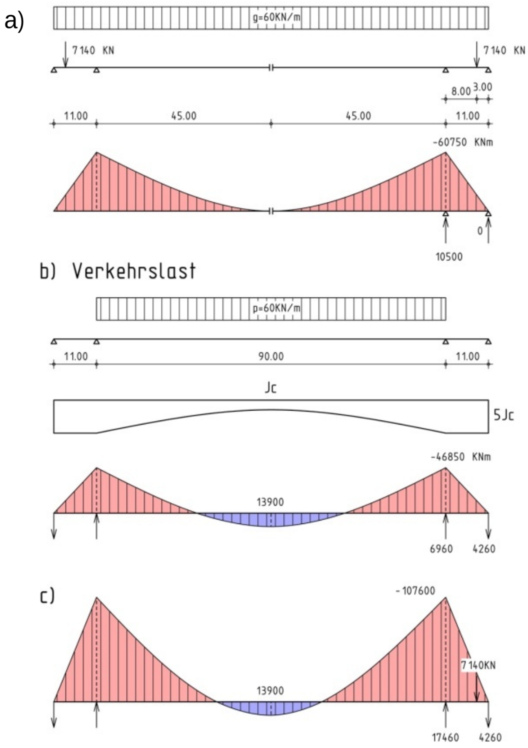


Fig. 7.3: Bending moments of a double bascule bridge; a) permanent loads, b) traffic, c) permanent laods + traffic

7.2.5 Comparison of the DBBB with a single bascule beam bridge (SBBB)

The live load moments of the SBBB are that of a beam with a span of 44 m, that is 13.200 kNm.

The comparison shows

1. The governing moments of the bridge deck are basically the same.
2. The governing force of the rotation bearing is that under permanent loads (6.900 kN). The live load (-4.200 kN) reduces it, but does not invert it.
3. The force of the tensile rod is about 70 % bigger.
4. The governing moment of the balance beam is increased by about 12 % from 64.300 kNm to 72.100 kNm.
5. The governing moment at the base of the tower is increased from 7.800 kNm to 42.900 kNm.

This is unproblematic due to the big dimensions of the tower.

7.3 Summary

The presented innovative system of a double balance beam bridge allows to take all loads by a simple blockage of the rotational axis.

Compared to a double flap bascule bridge it allows a substantial reduction of the cost of the bascule bridge pier – especially when situated in water and/or poor soil and of the construction depth of the bridge deck.

Compared to a single balance beam bridge it allows to double the span. The increased normal force of the tensile rod and bending moment at the bottom of the tower may be absorbed without major problems.

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