Movable Bridges in Belgium

Dr. Ing. L. Cypers
Ministry of Public Works, Belgium

1 Historical development

Movable bridges have been built for centuries. They are usually intended for linking roads across a waterway while, at the same time, allowing free navigation on the waterway. Alternative solutions like tunnels under the waterway or a fixed bridge at a sufficient height above the waterway are not always possible for technical or economical reasons.

Until the beginning of the twentieth century movable bridges in Belgium were driven by manpower. In the first half of the twentieth century more and more mechanical equipment became prominent.

Hydraulic working devices for movable bridges in Belgium were first studied in 1954. A first such bridge went into operation in 1957. A major reason for using hydraulic devices was because of the lack of ability of electromechanical drives to fulfill the law of motion for the bridges in a satisfactory way.

The problem was this: in order to obtain a short moving time the normal speed of the bridge had to be rather high: On the other hand, it was necessary to have a smooth, slow approach to the end position of the bridge.

The first solution to that problem was based on the skill of the bridge operator. By successively connecting and disconnecting the electromotor he more or less succeeded in obtaining an end position without excessive shocks. Obviously, heavier bridges did not help the problem due to their limited speed reduction. Neither was the use of a mechanical brake or electrical resistances in the rotor circuit satisfactory.

A technically acceptable solution in the mid 50's was only possible by using direct current driving motors, connected to a Ward Leonard generator set. It was possible to realise a slow approaching speed, which was not dependent on external disturbances, by using a feed-back signal of a tachymetric dynamo. Such a complex and costly solution was of course only possible for the more important bridges.

A technically good and economically acceptable solution was looked for in the field of hydraulic equipment. At first, hydraulic systems using constant flow pumps were considered. The speed regulation with that type of pump had to be achieved by applying flow-regulating valves. The real flow through such valves depended on the viscosity of the oil. At that time oil viscosity varied within great limits depending on the ambient temperature which, for movable bridges, could vary a lot. Further difficulties resulted from the fact that, at low speed, an important fraction of the pump power is converted to heat in the flow-regulating valves necessitating the use of excessively large oil-containers or of oil cooling machinery. Therefore, the use of constant flow pumps was abandoned.

Volumetric pumps with variable flow offered a solution. Since the first experiment in 1957, hydraulic devices have produced such good results that nowadays almost every new bridge is designed that way. In this article a survey of the different types of bridges that have been constructed in Belgium over the last 25 years will be given. Special attention will be devoted to the characteristics of the driving mechanism.

2 Draw-bridges

A schematic view of a draw-bridge is given in *figure 1*. Bridges of this type are frequently used for spans up to 25 m. They have an unlimited pass to the navigation and need only a small underground structure. Their superstructure too can be built very economically. In its closed position the resulting moment of the counterweight is usually less than the moment of the bridge structure. Therefore no bolting mechanism has to be installed to keep the bridge closed. In its open position the bridge is blocked by closing a mechanical brake in the older electromechanically driven bridges or by the pressure in the hydraulic cylinder in the new ones.

It was on this type of bridge that the first experiments with hydraulic drives were carried out. The basic concepts of hydraulic drives have since been unchanged. The two cylinders are mounted horizontally parallel to the axes of the main girders in an shallow cellar under the road. The supports allow the rotation in the vertical plane of the cylinder due to the rotation of the bridge as well as the slight rotations in the horizontal plane due to misalignment. A schematic, simplified drawing of the hydraulic circuit is given in *figure 9*.

As a minor inconvenience of this type of bridge, the fact can be quoted that eight rotation points on the bridge have to be maintained. Objections about aesthetic aspects are sometimes raised by urban development officials because of this.

A survey of draw-bridges in Belgium is given in *table1*.

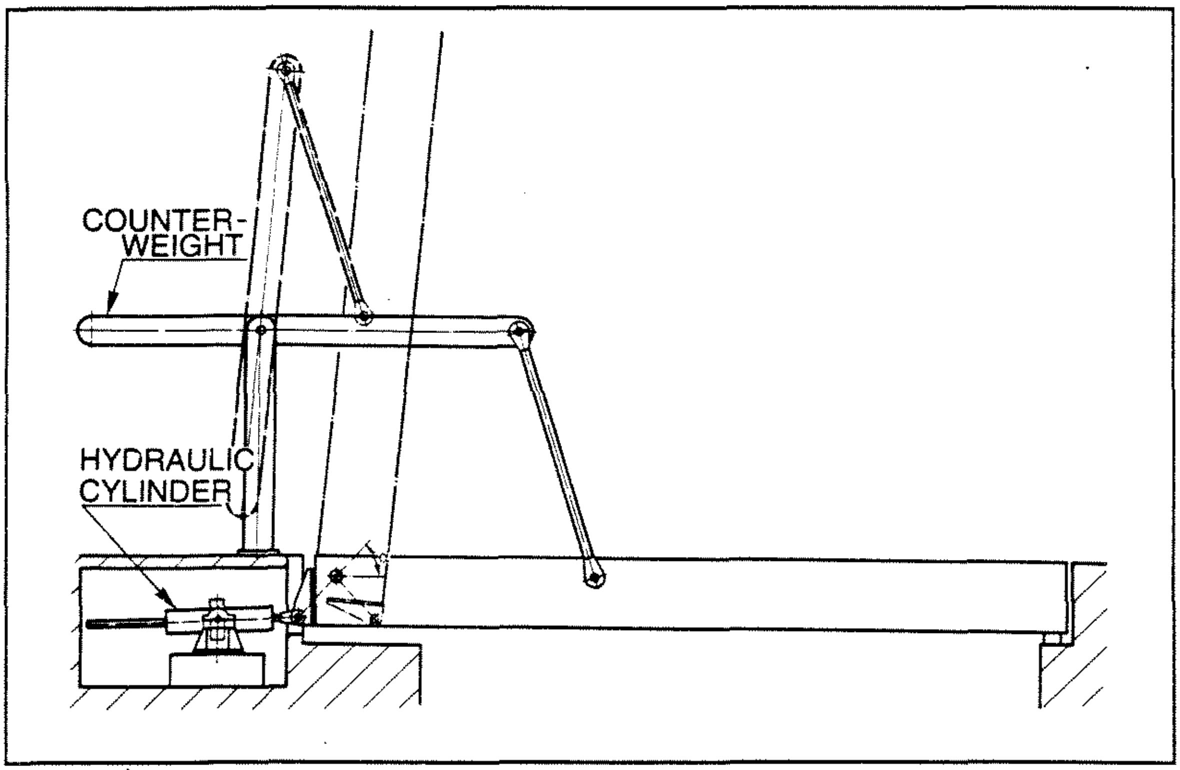

Fig. 1: *Schematic view of a draw-bridge*

Bridge	Span x width (m x m)	Cylinders	Year of construction	Remarks
Ninove	—	—	1957	
Merendree	—	—	1960	
Steenbrugge	12,6 x13	—	1960	
Brugge - Verbindingssluis	12 x 5,5	—	1971	
Lessives	12,45 x11	2 x 350 kN	1972	
Brugge - Weg & spoorwegbrug	23 x 5,5	2 x 500 kN	1972	
Oostende - Visserijbrug	24 x10	2 x1150 kN	1975	
Nieuwpoort - Gravensas	8 x 9	2 x 300 kN	1979	
Nieuwpoort - Veurnesas	8,5 x 9	2 x 300 kN	1979	
Merksem 1 & 2	16 x10	2 x 500 kN	1980	
Grimbergen	23 x11	2 x 550 kN	1982	
Lokeren	13,125 x10,55		1987	

Table 1: *Draw-bridges in Belgium*

3 Bascule bridges

To avoid a number of rotation points the counterweight can be fixed to the main girders as shown in *figure 2*. Such a solution inevitably means the construction of a deep cellar. Smaller bridges can be constructed without a counterweight. In Belgium this has been done for a span of up to 20 m and a width of 13 m. In both cases aesthetic bridges having uncomplicated mechanisms can be built.

To cope with the need for longer spans bascule bridges of a design shown in *figure 4* are used. In Belgium, some 13 bridges of that type with a span of over 60 m have been constructed. Most of them are used for road and railway transport across sea locks in the ports of Zeebrugge and Antwerp. As they have to be open for several hours during locking of ships, a bolting mechanism for the open position is provided. As a rule, railway bridges also have a bolting mechanism for the closed position.

A survey of bascule brides in Belgium is given in *table 2*.

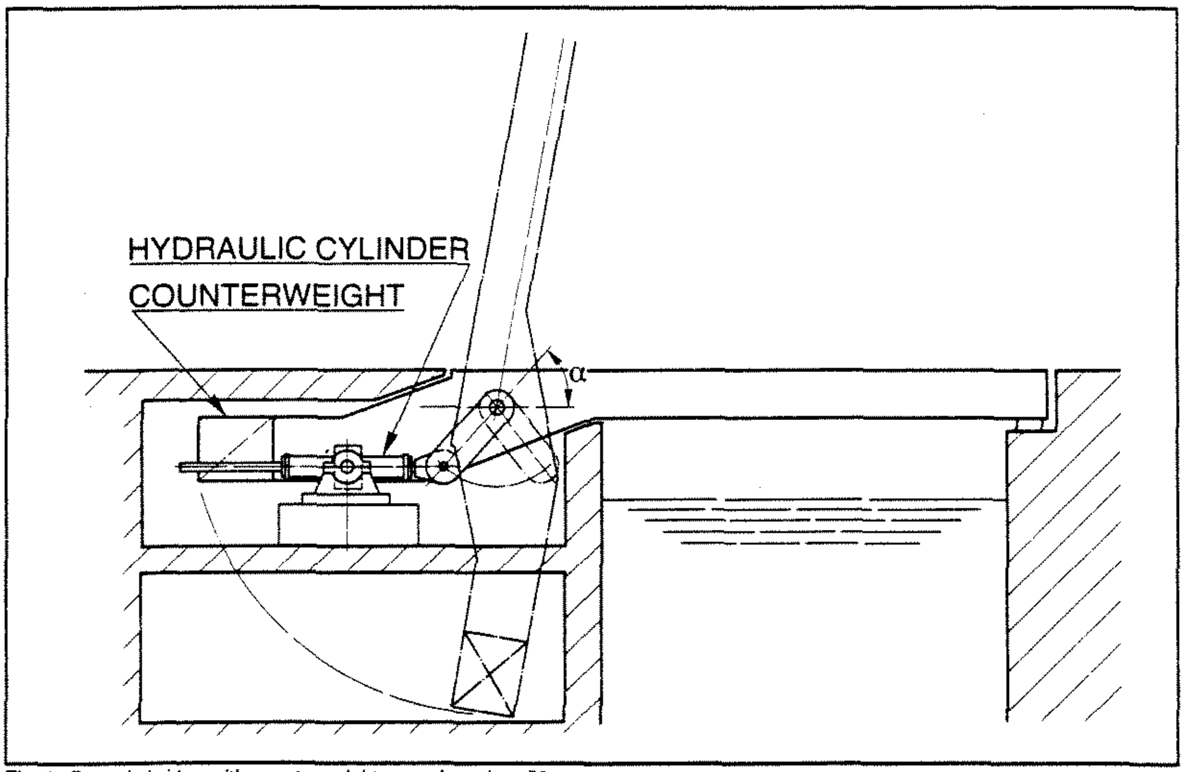

Fig. 2: *Bascule bridge with counterweight, span less than 50 m*

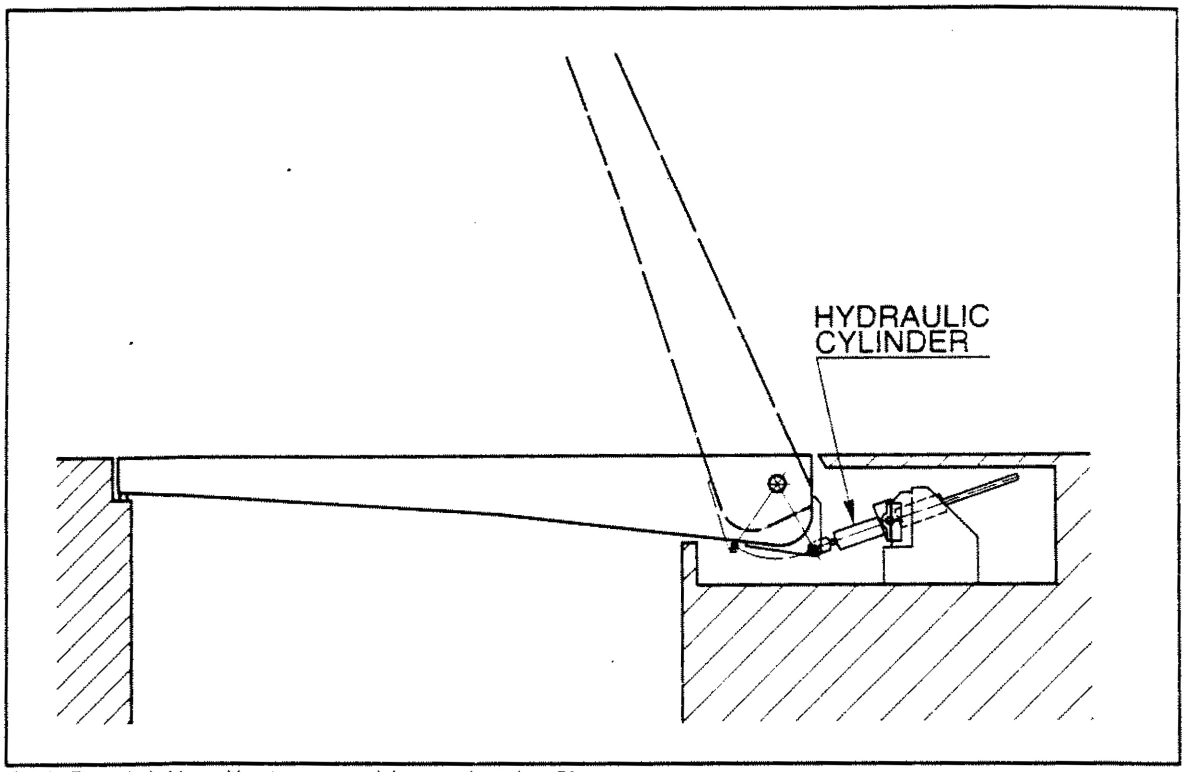

Fig. 3: *Bascule bridge without counterweight, span less than 50 m*

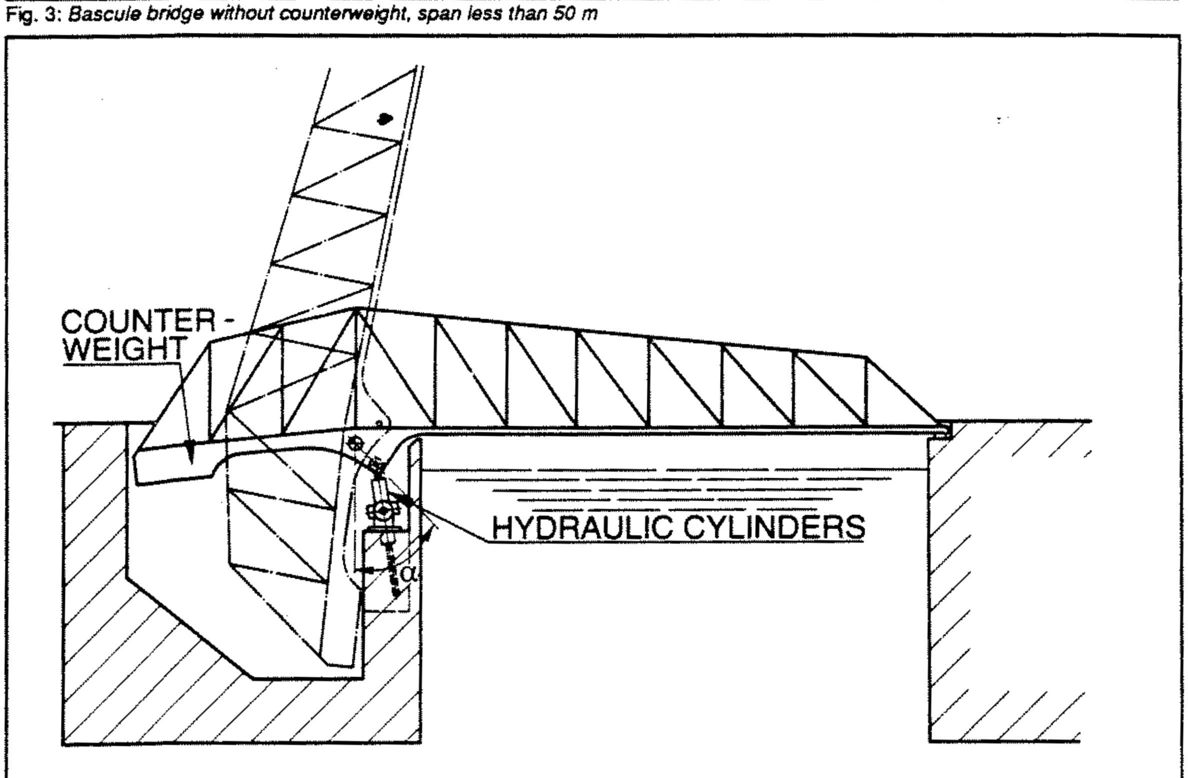

Fig. 4: *Bascule bridge, span over 50 m*

Bridge	Span x width (m x m)		Cylinders	Year of construction	Remarks
I. Span less than 50 m					
Zelzate	(2 x 31)	x20,5	2 x 700 kN	1968	2 flaps
Mechelen - Coloma	15,7	x13	2 x 1000 kN	1969	
Oostende - Montgomery	12,5	x12	—	1971	
Oostende - Kapelle	15,7	x10,5	2 x 600 kN	1973	
Oostende - Mercator	12,5	x12	—	1974	
St Job in't Goor	9,72	x 4,5	2 x 700 kN	1975	without counterweight
Mechelen - Plaisance 1 & 2	19	x 9,5	2 x 3000 kN	1979	without counterweight
Schoten	19,43	x13	2 x 2500 kN	1979	without counterweight
Brugge - Montgomery	13	x10	—	1979	without counterweight
Wijgmaal	16,57	x11	2 x 2200 kN	1986	without counterweight
Hofstade	13,6	x11	2 x 3000 kN	1986	without counterweight
Boom	26,8	x20,8	2 x 3000 kN	1987	
Tildonk	13,6	x11	2 x 1900 kN	(1990)	without counterweight
II. Span over 50 m					
Zandvliet	62,9	x13,5	2 x 5230 kN	1966	
Kallo 1 & 2	63	x13,5	2 x 5000 kN	1975	
Kapelle o/d Bos 1 & 2	63	x12,2	2 x 10000 kN	1976	
Dudzele	50	x11,6	—	1980	
Zeebrugge 1, 2, 3 & 4	66,6	x10	2 x 5500 kN	1980	
Frederick Hendrik	62,9	x10,2	2 x 5230 kN	1984	
Oudendijk	74	x10,2	2 x 7500 kN	1985	
Berendrecht	74	x10,2	2 x 7500 kN	(1988)	

Table 2: *Bascule bridges in Belgium*

4 Lift bridges

Whereas the previous types of bridges are opened by a rotation of the bridge around a horizontal axis, lift bridges are opened by a *translation into the vertical plane.*

The forces needed to open lift bridges are independent of wind, which is a considerable advantage. For lift bridges with a counterweight of the type shown in *figure 5* the force needed to operate them can be limited. The main constituents of these forces are:

1 The force needed to overcome the friction in the turning wheels of the steel cables connecting the bridge *with the counterweight;*

2 The force needed to overcome the unbalance, i.e. the intentional unbalance between the weight of the bridge and the counterweight and the unintentional *unbalance due to snow load on the bridge.*

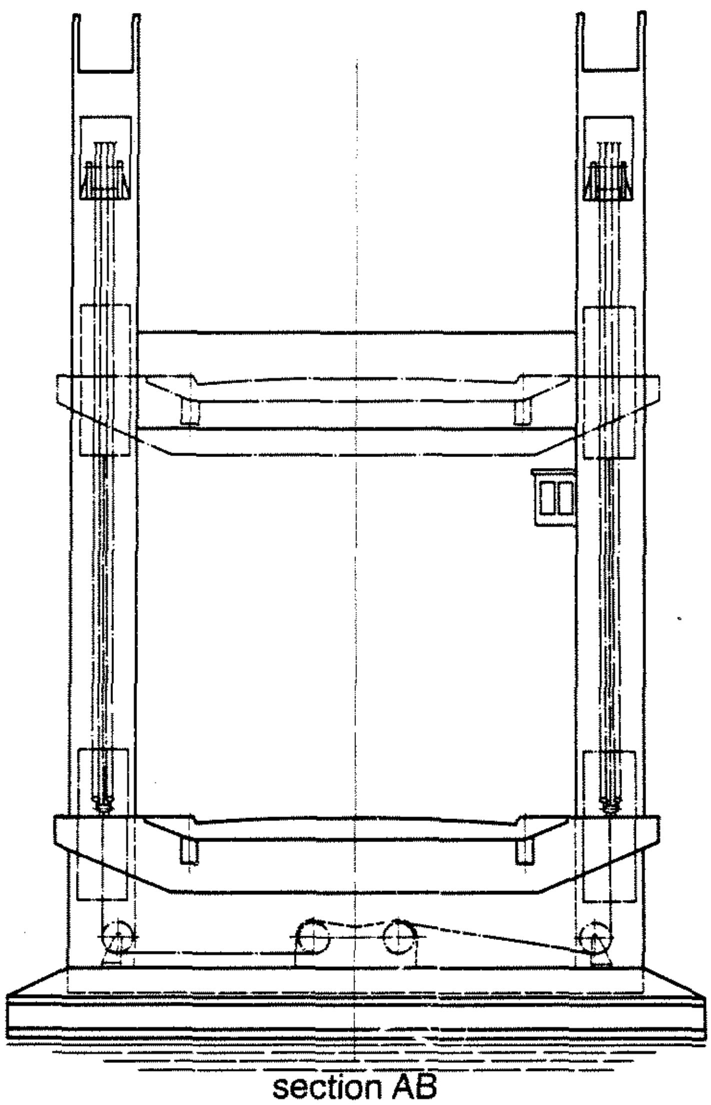

Fig. 5: *Lifting bridge with counterweight (lifting height less than 10 m)*

To avoid the heavy concrete structure needed to house the turning wheels and the counterweight, several lift bridges without counterweight, the type shown in *figure 6*, have been designed. Only slender columns are needed as a suspension for the hydraulic cylinders.

Some lift bridges have been designed without counterweight and with the cylinders mounted underground as shown in *figure 7*. The main reason for such a solution was the desire to avoid any superstructure.

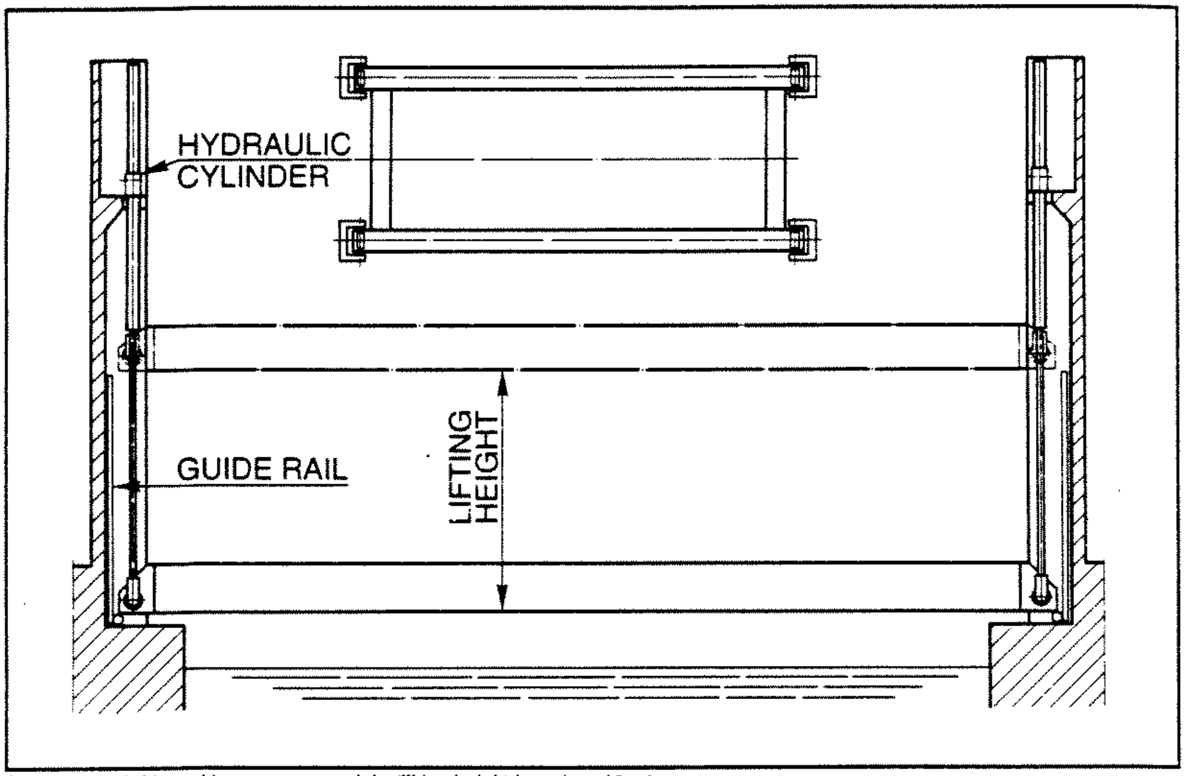

Fig.6: *Lifting bridge without counter weight (lifting height less than 10 m)*

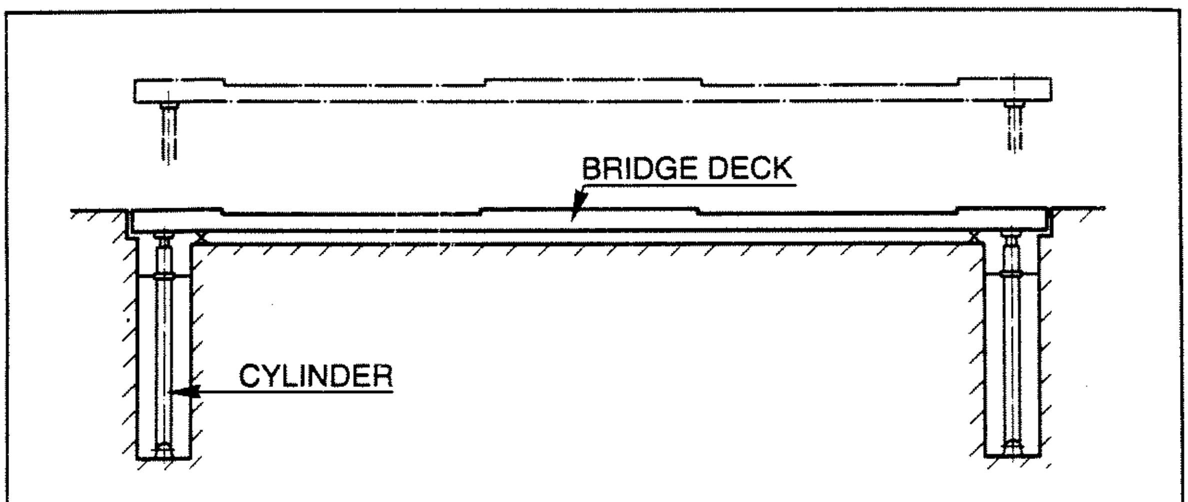

Fig. 7: *Lift bridge without counterweight and with the cylinders under the bridge deck*

Common to all hydraulically driven lift bridges is the need to synchronise the movement of the four (or sometimes two) driving cylinders. One solution is shown in *figure 10.* A synchronisation cylinder is used to equalise the flow to both cylinders upstream and downstream. The low-pressure sides of the left-bank-upstream and right-bank-upstream cylinders are connected as well as the low and high pressure sides of the left bank cylinder. The same applies to the downstream cylinders. The flow to each cylinder is then the same and an uniform movement of the bridge is achieved. Other solutions use feedback systems based on a measurement of the inclination of the bridge.

Lift bridges driven by hydraulic cylinders are usually limited to a maximum lifting height of less than 10 m. For greater heights lifting bridges of the type shown in *figure 8* are constructed. The counterweight is suspended to the bridge structure by steel cables. The driving steel cables are connected to the counterweight or sometimes to the bridge structure. The winches are driven by hydraulic rotating axial piston pumps or by direct current, electronically regulated electromotors. This type of bridge is in fact the only one in Belgium in which electromechanical driving devices compete with hydraulical ones.

A survey of lift bridges in Belgium is given in *table 3.*

Bridge	Span x width (m x m)	Cylinders		Year of construction	Remarks
I. Lifting heights below 10 m					
Erembodegem	35 x10	2 x 125 kN	3,88	1973	
Ninove	35 x10	2 x 125 kN	3,88	—	
Geeraardsbergen	26 x10	4 x 600 kN	—	1975	without counterweight
Leuven	20,3 x 8,2	4 x 650 kN	6,02	1979	without counterweight
Brugge - Dammepoort	9,48 x28,13	4 x 450 kN	3,3	1982	without counterweight
Oudenaarde	37,6 x11,3	—	6,15	1982	without counterweight
II. Lifting heights above 10 m					
Grimbergen	37,7 x11,6		34,1	1968	
Humbeek	37,7 x11,6		34,1	1968	
Tisselt 1	37,7 x11,6		34,1	1968	
Vilvorde	55,8 x30,96		27,5	1971	
Tisselt 2	55,8 x30,96		27,5	(1988)	electromechanical drive

Table 3: *Lift bridges in Belgium*

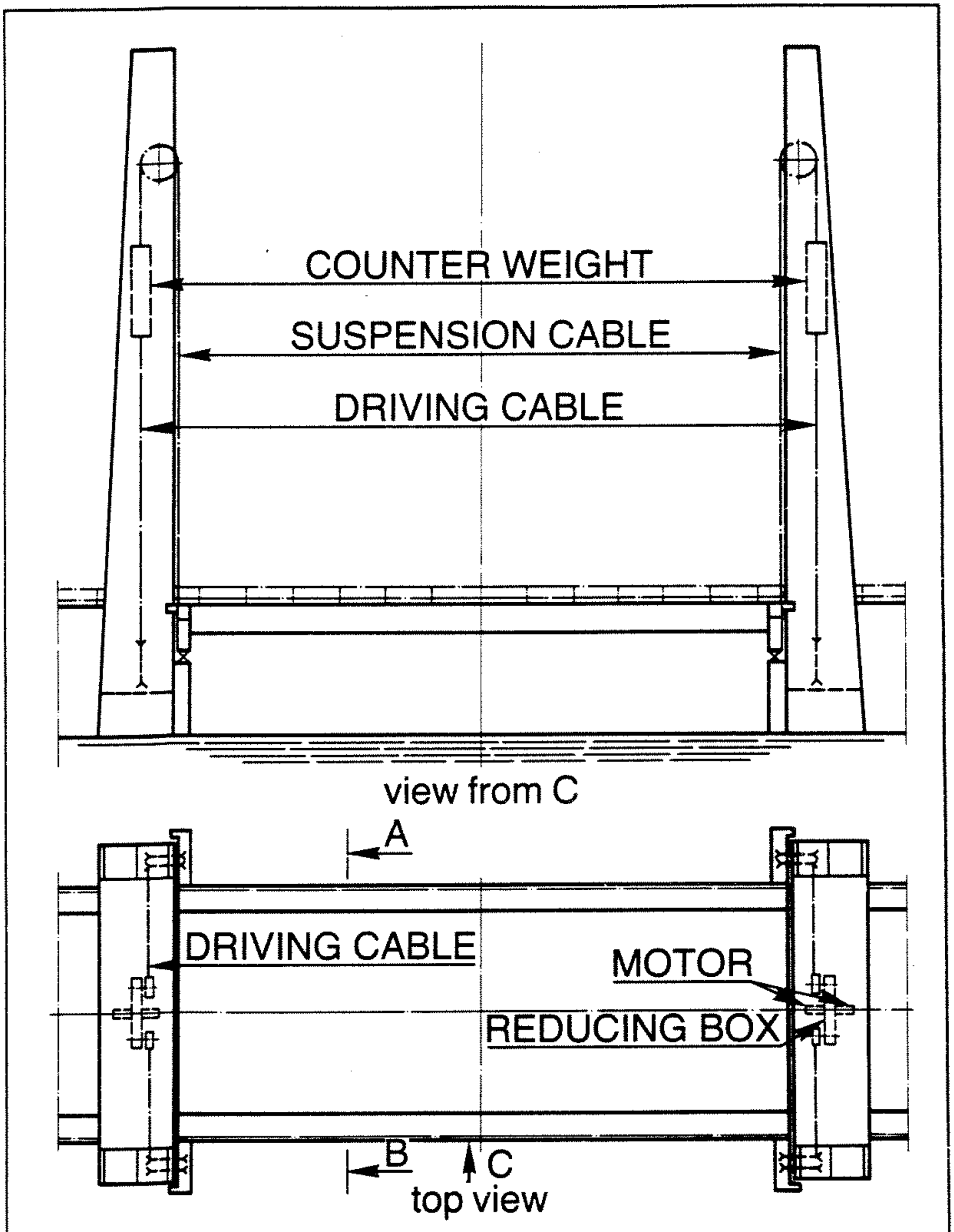

Fig. 8a: *Lifting bridge, lifting height more than 10 m*

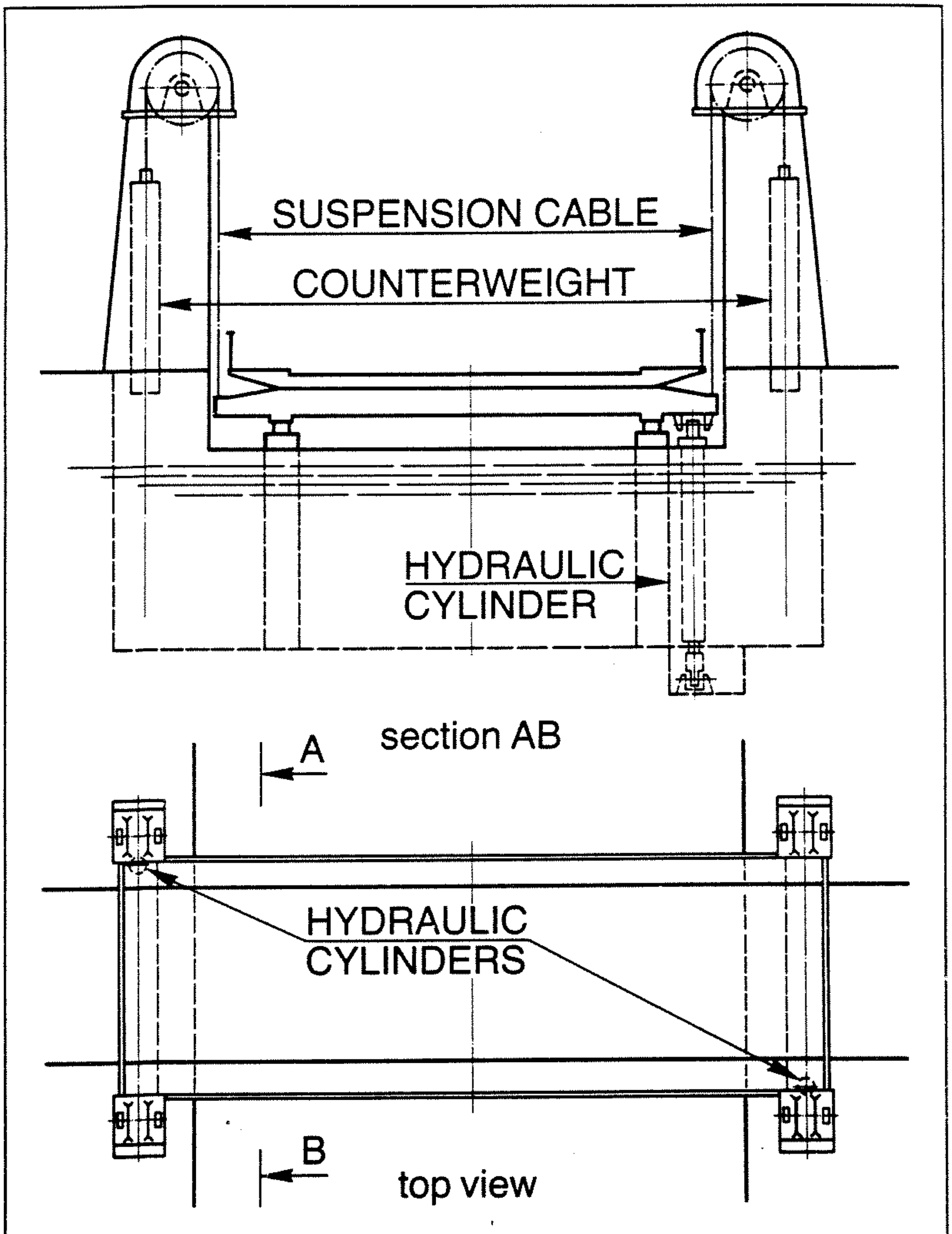

Fig. 8b: *Lifting bridge, lifting height more than 10 m*

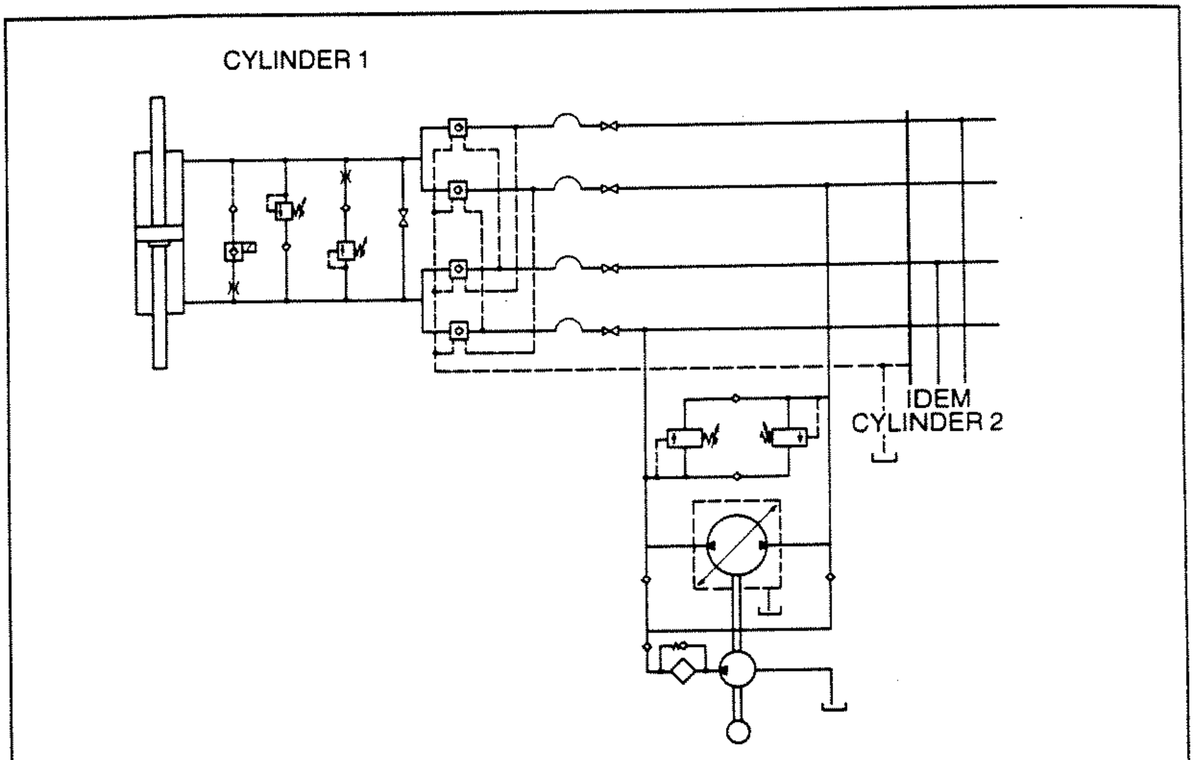

Fig. 9: *Simplified scheme of a draw-bridge, hydraulic circuit*

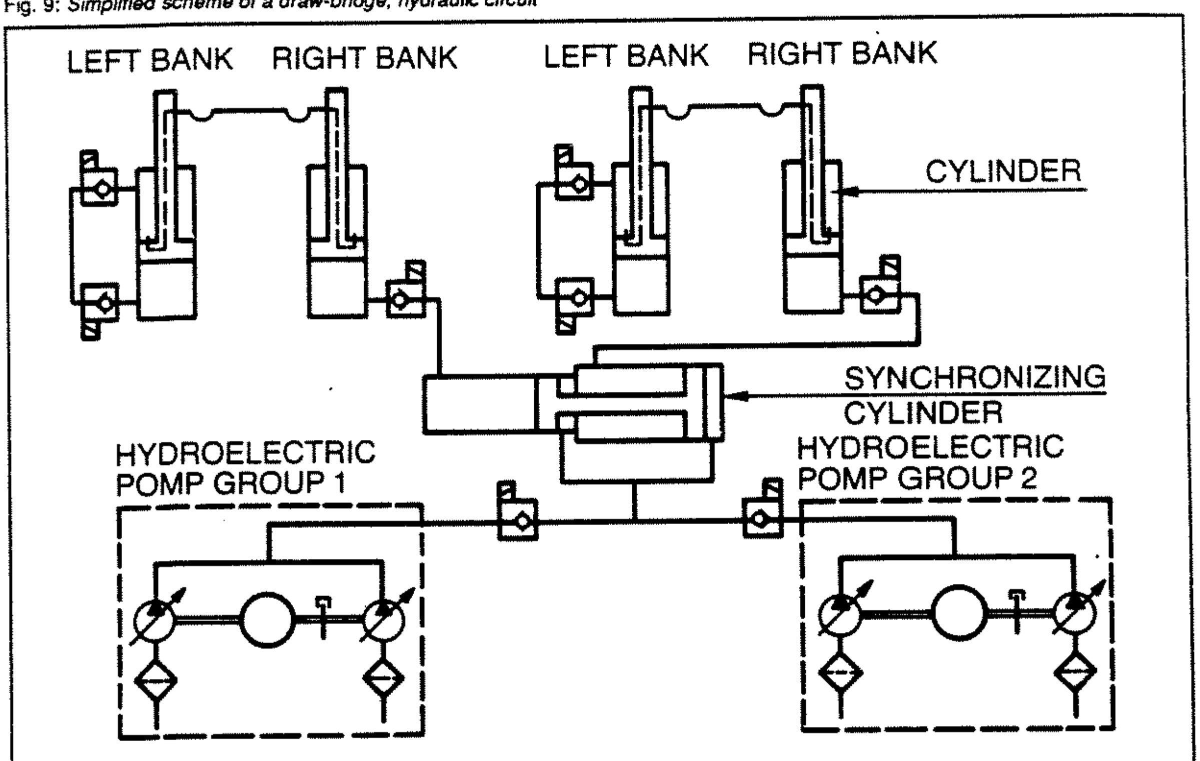

Fig. 10: *Simplified scheme of a lift bridge, hydraulic circuit*

5 Conception and design considerations for driving mechanisms

It is obvious that every type of bridge and in fact every bridge, has its own specific conception and design. Some general considerations, however, can be given.

In the design of driving mechanisms as in most engineering design, a general rule holds: the less complicated the better. So it is preferable to only partially counterweight a *bridge to avoid the use of a bolting mechanism in the* closed position.

An elimination of some elements, for example the counterweight possibly with its suspension cables and turning wheels, ought to be considered even if the driving cylinders become larger.

The dimensions of the driving cylinders depend among other things upon the wind force and the snow load working on the bridge and upon the working pressure of the hydraulic system.

Wind pressure is the main force acting upon drawn bridges and bascule bridges. The pressure normally taken into consideration in Belgium amounts to 750 N/m^2 exposed surface of the bridge for bridges on waterways with sea-going vessels and 600 N/m^2 for bridges on inland waterways. It has been discovered that for bascule bridges with a span of over 60 m the wind load represents more than 90 % of the load that the driving mechanism has to surmount. As those bridges have to be designed to be kept open in heavy weather, bolting mechanisms are calculated for a wind pressure of 1500 N/m^2.

The working pressure in the hydraulic circuit is usually in the range of 140 to 160 bar or 210 to 230 bar. Components are calculated for a peak pressure of 1.5 times the working pressure.

Rotating points such as the main bridge rotation axis, the suspension points of the cylinders or the turning wheel bearings, are generally equipped with two-row roller bearings with an automatic or manual greasing system.

The manoeuvring time of the bridge is an important factor in dimensioning the hydraulic system. Normal opening or closing times for bridges are selected as follows:

1 Bridges on waterways with sea-going vessels:
   - road traffic less than 5,000 vehicles/day
     120 s for a span less than 50 m
     and 190 s for a span over 50 m
   - road traffic more than 5,000 vehicles/day
     95 s for a span less than 50 m
     and 150 s for a span over 50 m

2 Bridges on inland waterways
   - road traffic less than 5,000 vehicles/day
     75 s for a span less than 25 m
     and 120 s for a span over 25 m
   - road traffic more than 5,000 vehicles/day
     60 s for a span less than 25 m
     and 95 s for a span over 25 m

Fig. 11: *Ninove, draw-bridge (1957)*

Fig. 12: *Merksem, draw-bridge (1980)*

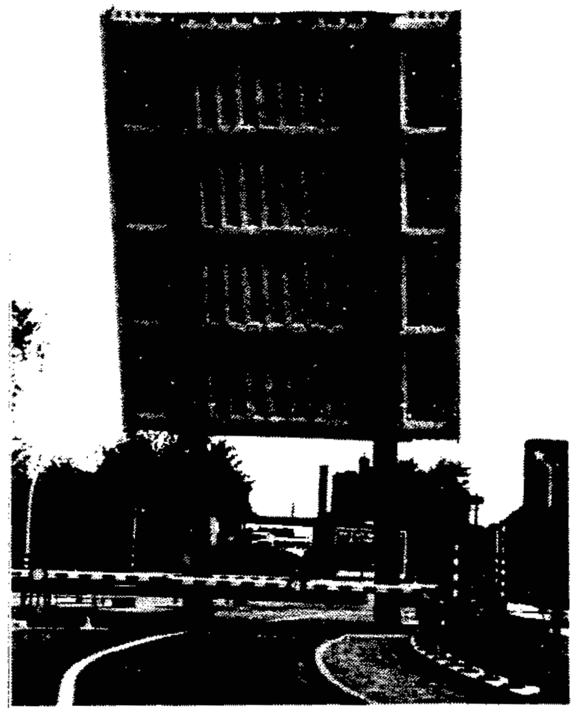

Fig. 13: *Brugge,*
Gentpoort - bascule bridge without counterweight (1979)

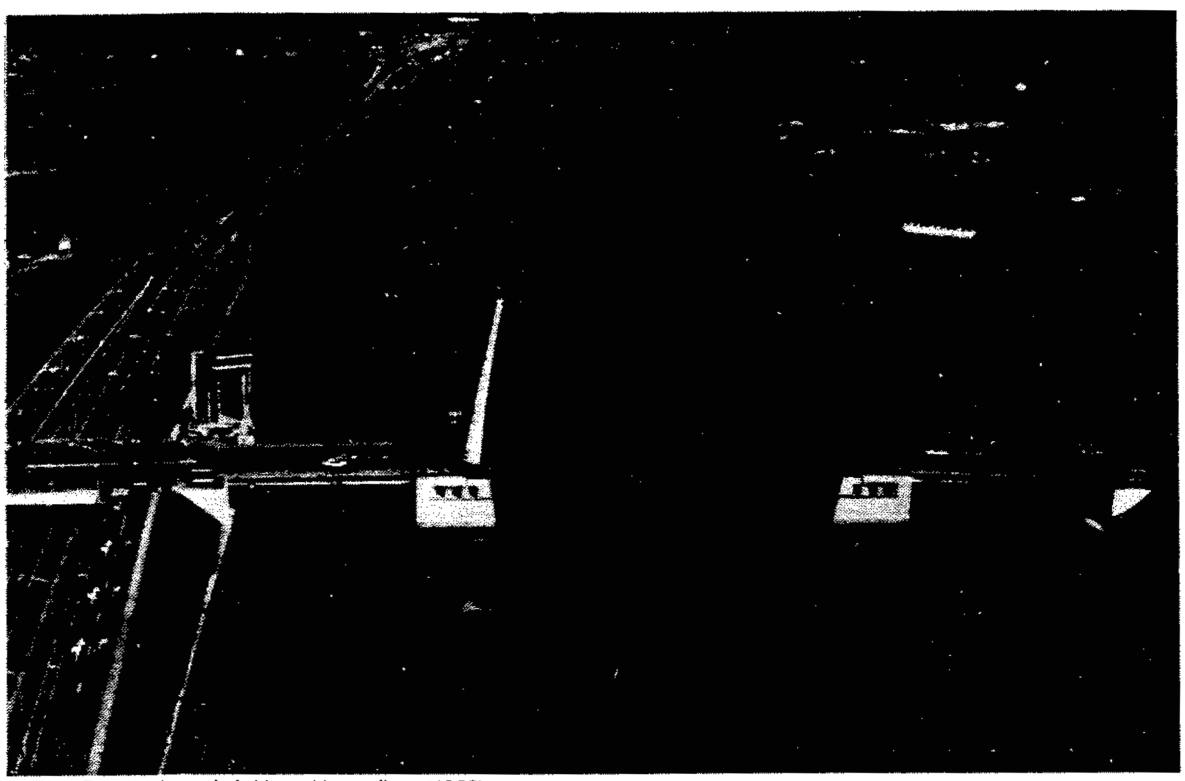

Fig. 14: *Zalzate, bascule bridge with two flaps (1968)*

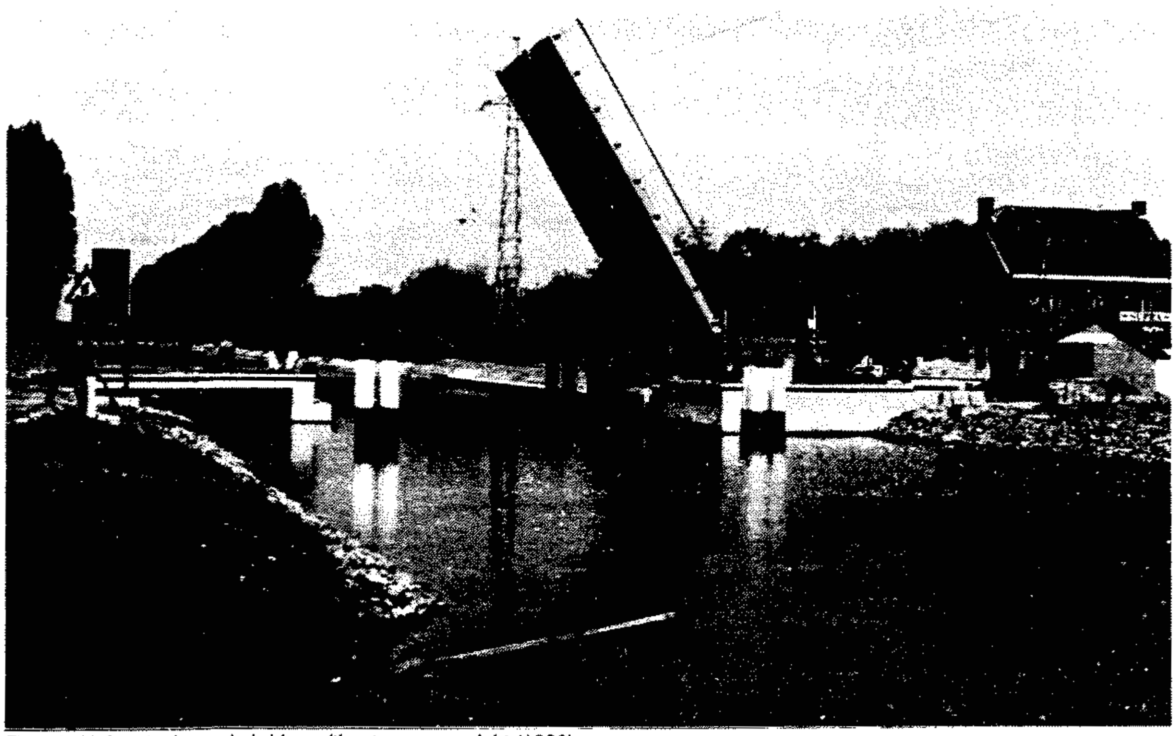

Fig. 15: *Hofstade, bascule bridge without counterweight (1986)*

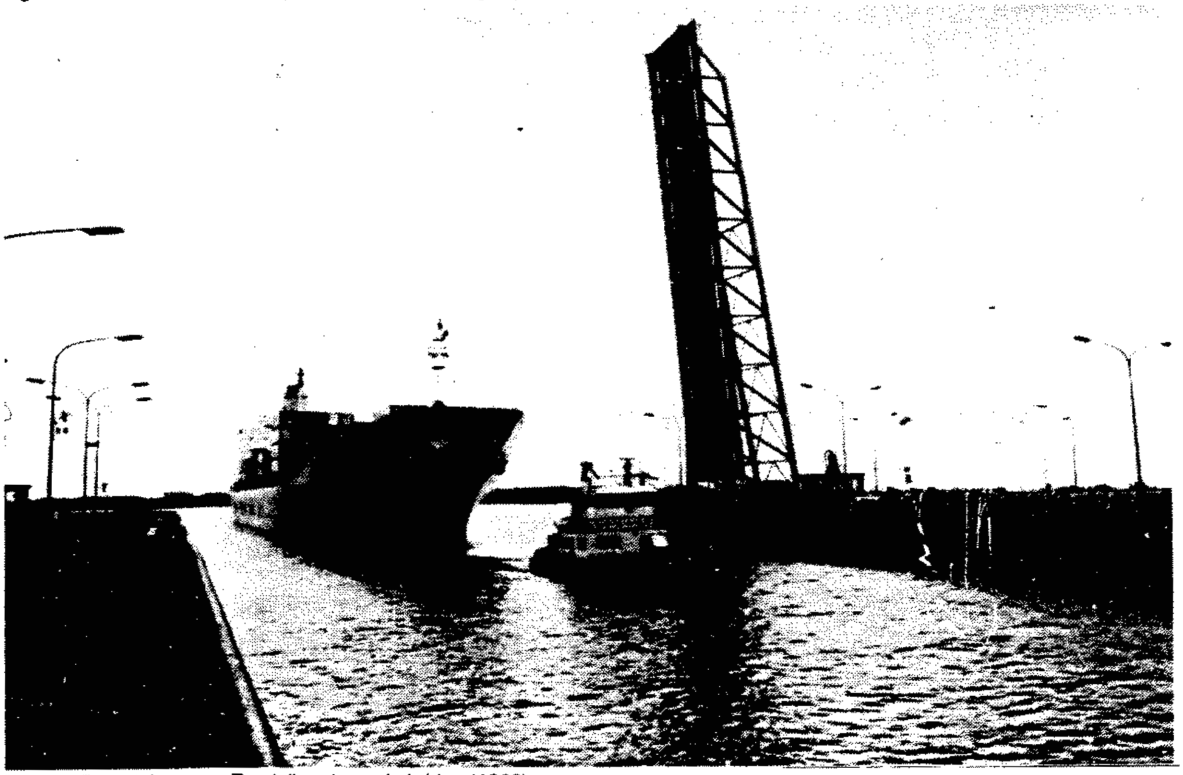

Fig. 16: *Port of Antwerp, Zandvliet - bascule bridge (1966)*

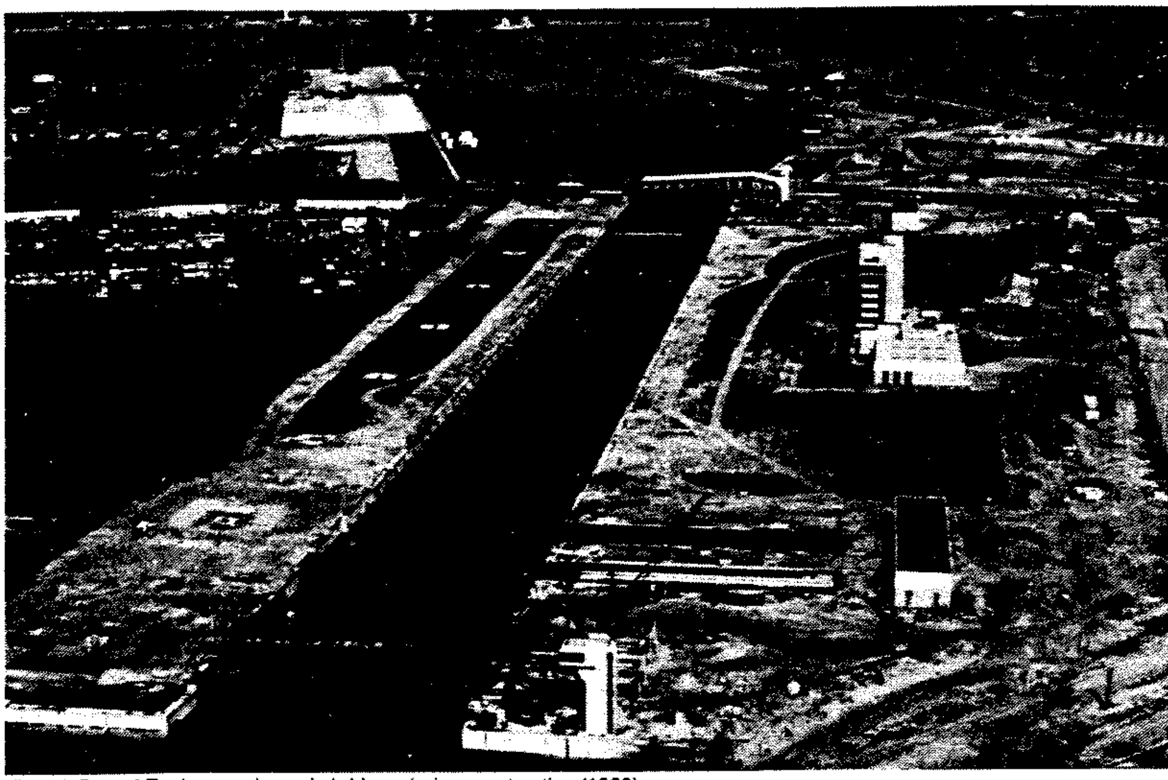

Fig. 17: Port of Zeebrugge, bascule bridges during construction (1980)

Fig. 18: *Port of Zeebrugge, bascule bridges during construction (1980)*

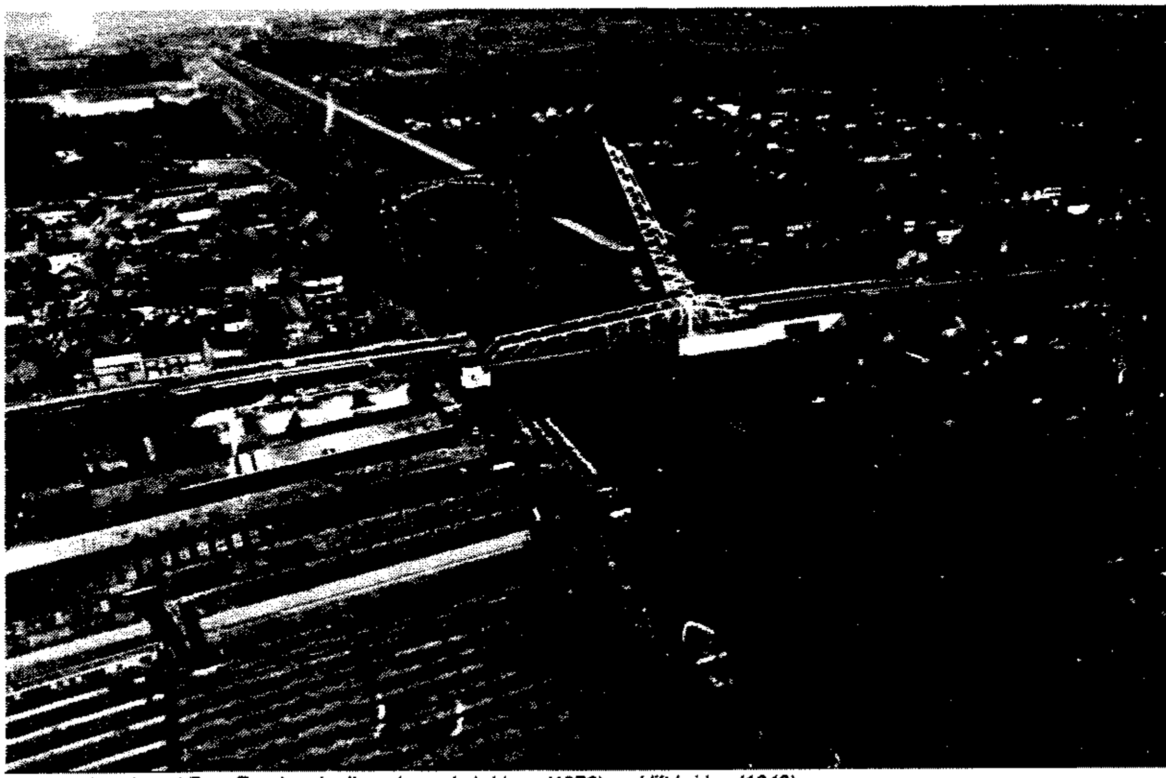

Fig. 19: *Kapelle o/d Bos, Road and railway bascule bridges (1976) and lift bridge (1948)*

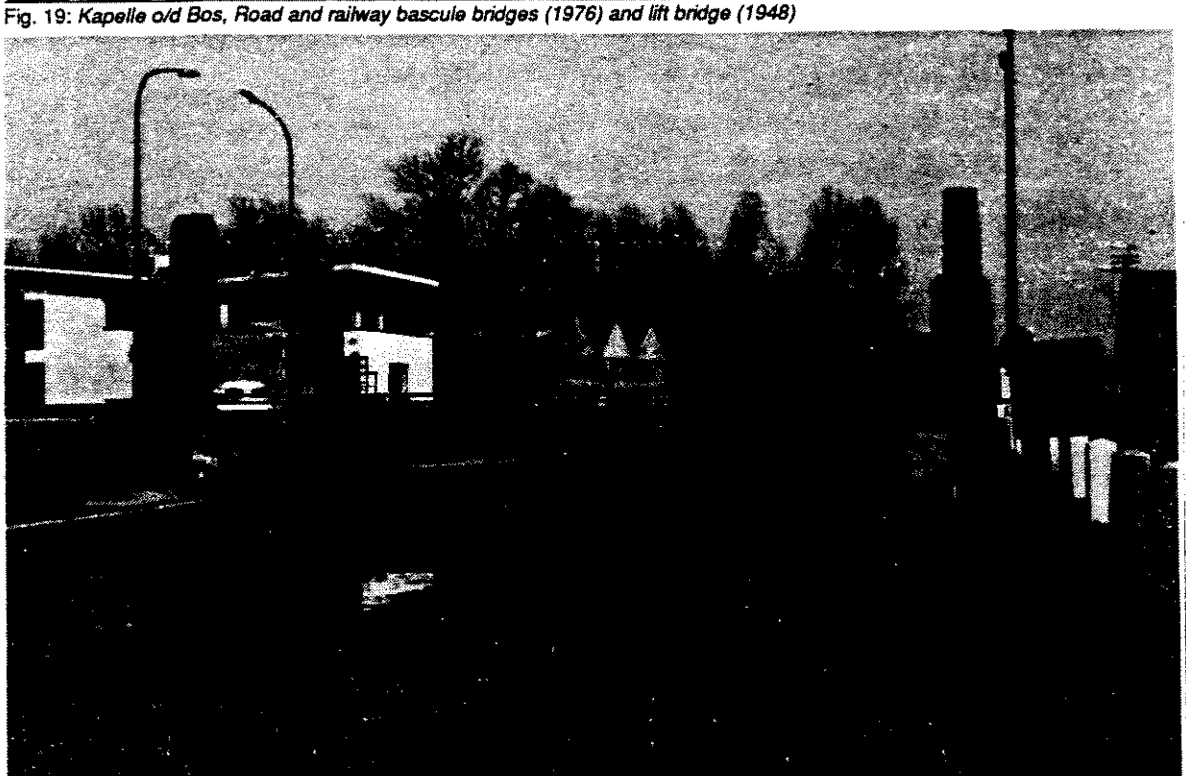

Fig. 20: *Ninove, lift bridge with counterweight (1974)*

Fig. 21: *Leuven, lift bridge without counterweight (1974)*

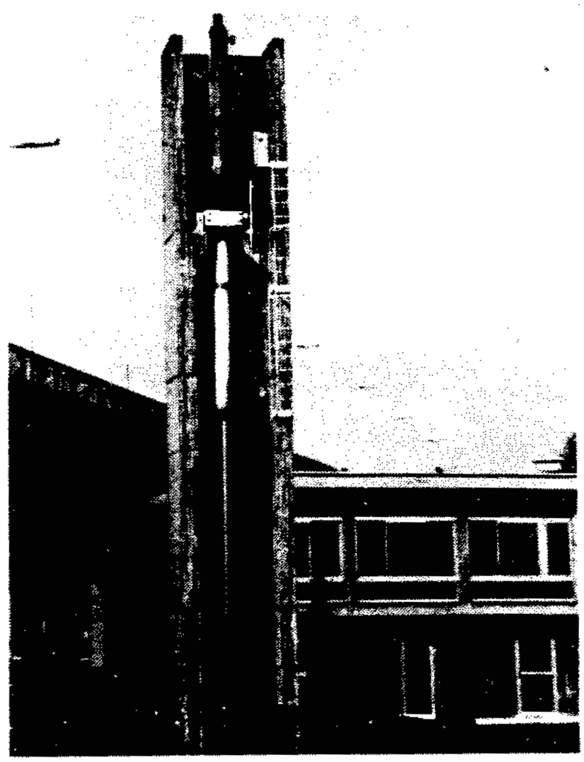

Fig. 22: *Leuven, lift bridge - hydraulic cylinder*

Fig. 23: *Oudenaarde, lift bridge without counterweight (1982)*

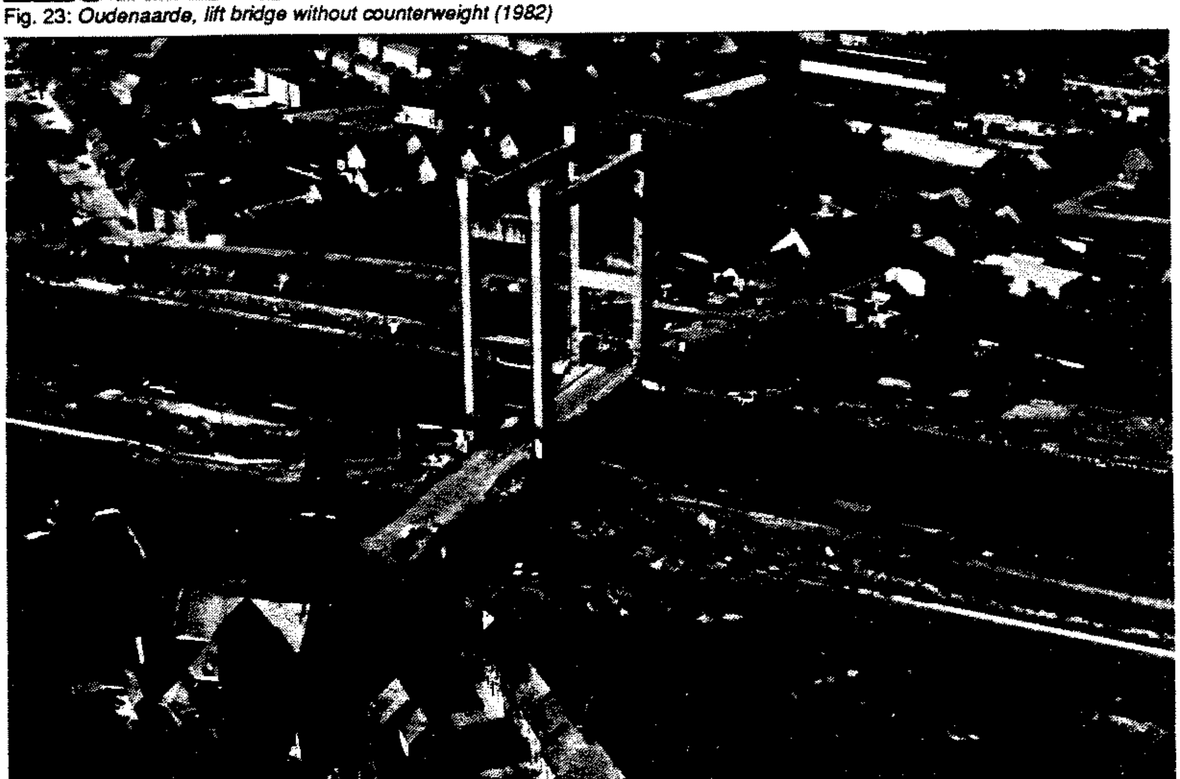

Fig. 24: *Humbeek, lift bridge (1968)*

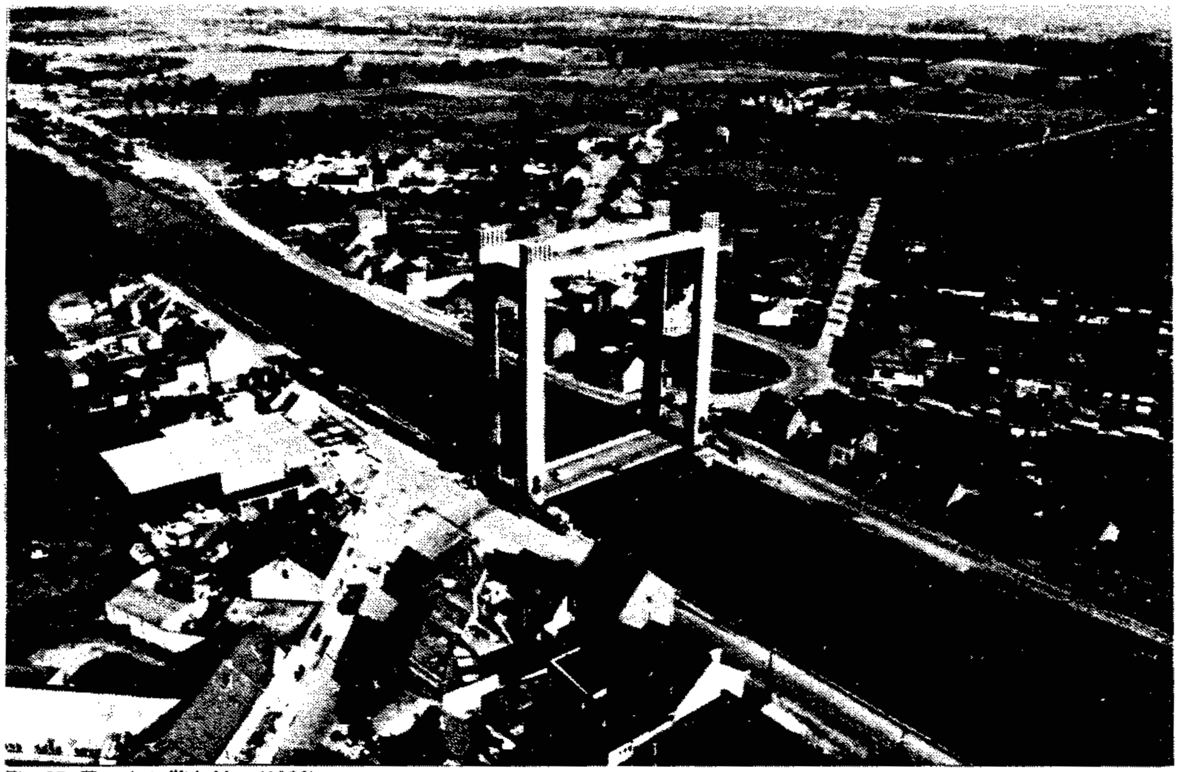

Fig. 25: *Tisselt 1, lift bridge (1968)*

Fig. 26: *Vilvoorde, lift bridge (1971)*

Notes