



## PORT-SAID SINGLE LEAF BASCULE BRIDGE

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**Abstract:** Movable bridges are special structures that can change position to allow navigation across waterways. They are composed of structural, electro-mechanical, hydraulic and control systems. Bascule Bridge types constitute by far of majority of movable bridge designs. The objective of this report is to present a detailed description of a new born bascule bridge in Egypt.

The new bridge design consists of six bays each of about 22 meters span and width of 14.8 meters, with movable bascule intermediate span, providing a navigation channel with infinite vertical clearance. The fixed bays are designed as composite multi-girder steel bridge with reinforced concrete slabs above, while the movable bay has been designed as plate girder with orthotropic steel deck and a light pavement. The movable bay dimensions have a length and width of 19.2 m and 14.8 m respectively. The spacing between balance weight supporting columns is 22 meters, allowing to a maximum open angle of 70 degrees. The operating system includes the gearbox, driving unit, shafts and brakes. The stroke length for the hydraulic cylinder reaches 2.4 meters.

The project is a good example of how functional and limited budget constrains can be taken into account in a movable bridge project. These constrains were considered starting from the concept design stage and extended up to the detailed drawing stage. The project required detailed inspection of material condition and structural configuration. The motor of the bridge lifting system has to be strong enough to operate the bridge against normal and higher wind pressures.

.Keywords: Movable, Suez Canal, bascule, fulcrum, bridge balance, lifting system.

### 1 INTRODUCTION

Egypt has been growth fast toward the road transport linking between its lands east and west. A lot of investments have been flooded in linking between Sinai and Cairo. The importance is not only strategically, but also commercially linking between the continents of Africa to Asia. Different bridges and tunnels have been constructed to cover the rapidly growth at different axis along the Red Sea. The clearance allowance for navigation through the Suez Canal had been achieved through deep under water tunnels, high cable stayed bridges or Movable ones. The suitable navigation clearance allows for the giant cruise ships, large vessels and container carriers to sail safely underneath. The Suez Canal cable stayed bridge, is an example for fixed type of bridges, having a maximum span of 400 m with two trapezoidal pylon of 150 m height having navigation clearance of 70 m, Figure 1.a. While the movable bridge allows for much lower vertical clearance above the High water level and can mechanically opened through either vertical lift, bascule or swing mechanisms. Movable bridges are more expensive to operate and maintain than fixed stationary ones. However, movable bridges usage have grown in different countries such as the most spectacular lift bridge in the world is the Bacalan-Bastide bridge, London iconic bascule bridge crossing Thames River. Egypt has the longest swing span worldwide as Al-Ferdan railway bridge across the Suez Canal consisting of two side spans of 150 m and a central one of 340 m

Figure 1.b. The bridge towers are 80 m high. The central spans of this asymmetrical movable bridge swings (150 + 170) meters around 2 tables one at each side of the Canal.



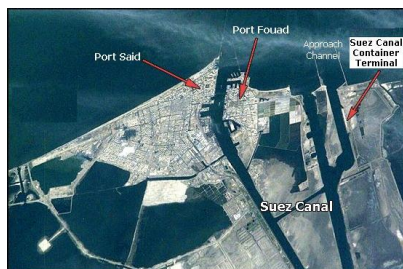
[a] Cable stayed bridge



[b] Al Ferdan swing bridge

Figure 1: Suez canal bridges

Today, as the Suez Canal has been enlarged at the location near Ismailia city. The traffic studies showed the need link port Said and Port Fouad cities, Figure.2.a, by means of a bridge to replace a small existing one, Figure.2. b, bridges B and A, respectively.



[a] Port Said- Port Fouad Map



[b] Old and New Azmy Bridges

Figure 2: Azmy Bascule Bridge

Different mechanism systems were studied for operating the movable bays. The main concerns in the mechanical system selection are the weight of the moving bay as its equilibrium has to be maintained during the open and close stages. This reflects on the importance of the best selection for the decking system to reduce the energy needed to control the bridge movements.

## 2 Azmy Bridge Description

Azmy bascule has a total length of 126 m and consists of 6 spans of varying lengths of 20 and 22 m. Five among the 6 spans are fixed while one is movable, Figure 3. The movable bay is an intermediate span with length of 22 m. The bridge width is about 15 m to accommodate 4 traffic lanes two in every direction.

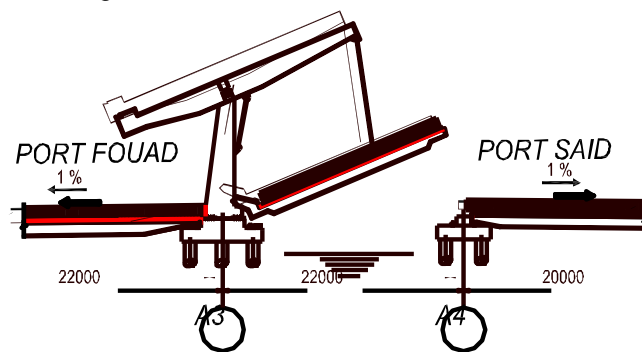


Figure 3: Azmy bridge movable bay elevation

The deck of the movable bay has been constructed as an orthotropic steel deck with a light pavement, that for two main reasons. Firstly, it has lighter weight with respect to other decking systems, and thus requires less power to rotate the leaf with smaller ballast counterweights. Secondly, they deliver the entire floor load, when the deck is rotated it transfers its load directly from the deck plate to the edge girders, i.e. reducing the internal forces in the upper and lower trunnion pins. The orthotropic deck, 15.0 m wide is supported by five main girders 2.90 m apart and transverse beams spaced every 2.0 m, having trapezoidal closed-rib system Figure 4. The pavement consists of a layer of tar mixed with cement of thickness 80 mm. While the approach bridge deck is designed as a multiple steel girder system acting in a composite fashion with a 25 cm reinforced concrete slab above

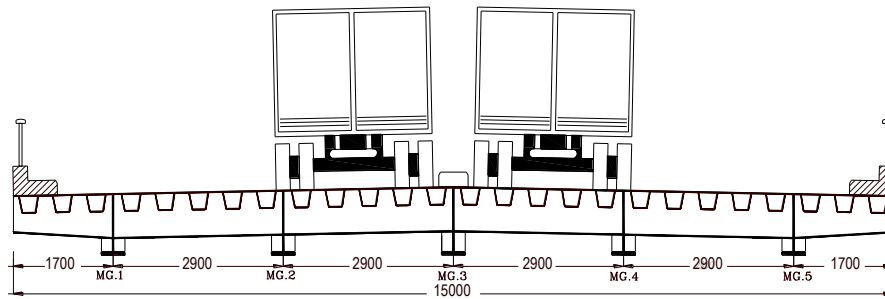


Figure 4: Loaded Intermediate section of the orthotropic bridge deck during test

The movable span is a bascule single-leaf orthotropic steel deck. The selected deck has the advantage of reducing the lifted bridge weight. The system is provided with steel lifting tower of about 12 m tall. The location of hydraulic cylinder connection with the column of the turnnion, the magnitude of the counter weight and its location are as given in Figure 5. The figure shows the geometric nomenclature for the four rotating pins as well as the hydraulic jack and counter weight at both the close and open positions that maintain the pressure in the hydraulic cylinder in a balanced and reasonable magnitude at the different cases of loading. In the opening position, the spacing between balance weight supporting columns is 22 m, allowing to a maximum open angle of the leaf is rotating to an angle of 70 degrees with the horizontal.

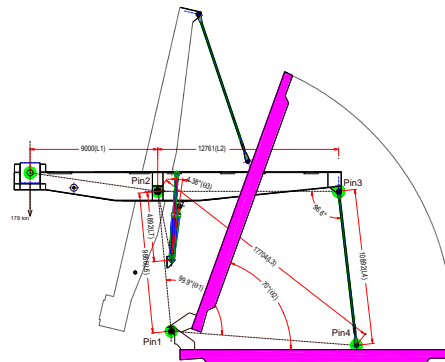


Figure 5: Movable bay geometric nomenclature

### 3 Movable Bridge Mechanism

The draw up system control the rotation with main components of this bascule bridge consisting of the movable steel deck, two tie rods, a balance frame including an overhead counterweight of 178 tons made of blocks of cast iron, a portal support H-frame and an operator's service building. The bridge opens like a lever on fulcrum. The fulcrum fits into the girder of the bridge and is made of a trunnion shaft attached to the leaf girder via a hub, and supported on bearings to permit rotation of the leaf. The trunnion hub-girder assembly form the pivotal element of the bascule mechanism to open and close the girder of the bascule bridge, power is supplied to the assembly by means of hydraulic cylinder system electrically equipped to

control the gradually bridge opening and closing. Figure 6. The opening and closing operations are performed by two servo-hydraulically controlled cylinder in the event of failure of either cylinder operation using only one cylinder is possible but at a reduced speed. The H-tower provides support to the main counterweight boom and to the pivot of the main operating struts. The H-tower consists of two columns connected with puller to the steel deck of the main girders. The puller is provided nearly to the end of the balance arm. Its function is to balance the steel deck loads during deck rotation on the trunnion pins. The mechanical studies for the operating system included both the kinematic study for the bridge, the analysis of the forces exerted on the bridge components, bridge stability at lock, balance arm trunnion pins and the bearing system. The stroke length for the hydraulic cylinder reaches 2.4 m

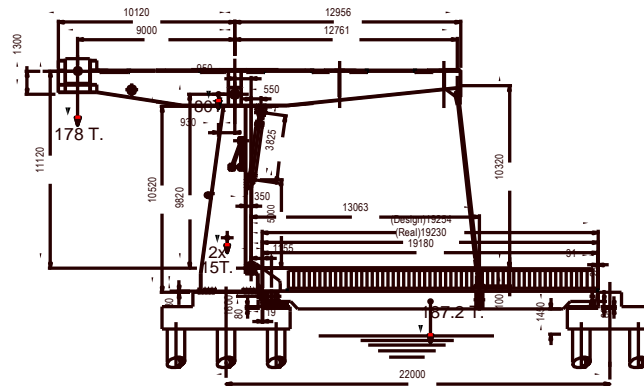


Figure 6: View of the rotating leaf in the close position

The movement of the bridge is controlled by a computerized system to follow all the necessary safety steps in each operation through service room located in one side of the high tower, Figure 7. The operating system is equipped with an electric motor, the gearbox and brakes. The system is provided with manual open or close system for the emergency cases.



Figure 7: view of the bridge during opening, showing operation Service operating room

#### 4 Force Analysis of The Movable System

Based on the lifting mechanism, the analysis of the induced forces on the different axes of bridge components, and the hydraulic cylinder during the different opening angles, three main loading cases have been considered. Firstly, case (a) considered the own weight of bridge and lifting components. Secondly case (b) considered the own weight of bridge, lifting components with the wind loading acting in the open direction. Thirdly case(c) considered the own weight of bridge, lifting components with the wind loading acting in the opposite to the opening direction. The design has determined the parameters of the location for hydraulic cylinder connection with the turnnion,

During operation, nearly the entire dead load is transferred to the bearings. The bearings have to possess also friction to mitigate the contribution of mechanism load at different opening angles. Additional forces also arise on the push-pull (hydraulic cylinder) due to the extra displacement in the vertical direction, Figure 8. a computer system is necessary to provide both the operator interface as well as a monitoring

system for the hydraulic power supplies and the control systems. A bascule bridge may be simply represented as a rotating mass with the entire weight of the bridge acting at its center of gravity. The balance of the bridge is thus dependent upon the offset of the bridge center of gravity from the point of rotation.

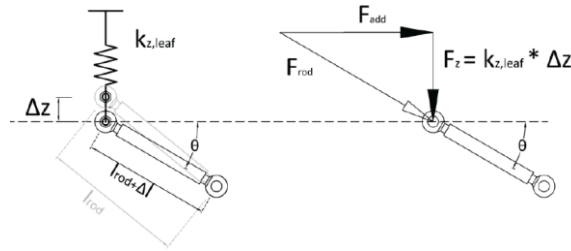


Figure 8: Hydraulic cylinder in a fully extended position.

## 5 Loading Combinations

The bridge has been designed to meet 90 tons traffic loading. In addition to the loading combinations stipulated by the relevant Egyptian design code for bridges. The following cases have been studied to include analysis of the bridge behavior and performance during different operating positions for alternative opening and closing operations. Four cases are investigated in the present study:

- a- Bridge opened with no wind.
- b- Bridge opened while wind acts in the same direction.
- c- Bridge opened while wind acts in opposite direction.
- d- Bridge in closed position and the pressure in the hydraulic cylinder is zero.

In cases a, b & c the calculation are checked at different angles to obtain the upper and lower limits for the calculated parameters. The considered angles from the start till the full opening are 0, 10, 20, 30, 40, 50, 60, 65, 70, 71 & 72 degrees. It is found that the critical case for bridge trunnion pin is the case (d). The frictional forces during operation can be reduced through a lubrication system. Further information can be found in the AASHTO movable bridge specifications that include the design guidance for the mechanical and electrical system.

## 6 Parametric Study of Wind Load Effect

The wind load direction affects the forces exerted on both the rotating and supporting system. Parametric study has been carried out to monitor such effect on the movable system at different opening angles. The study referred to the start open state of the bridge as comparative base line. The wind load has been considered in three conditions, positively when the wind load pressure equals to  $0.1 \text{ N/m}^2$  and applied with the raising direction of the bay and negatively in the opposite direction and lastly the wind pressure equals zero (case of no wind).

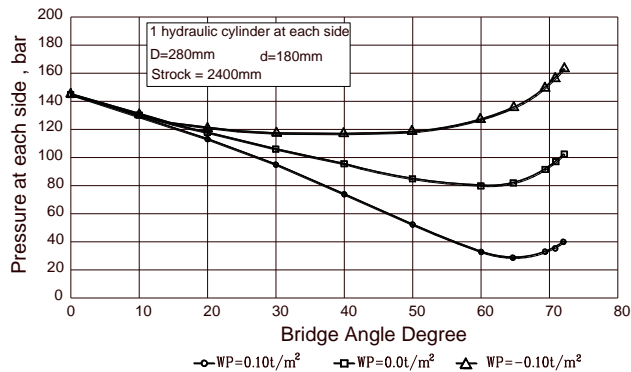


Figure 9: Driving Torque vs. bridge angle at different wind loads

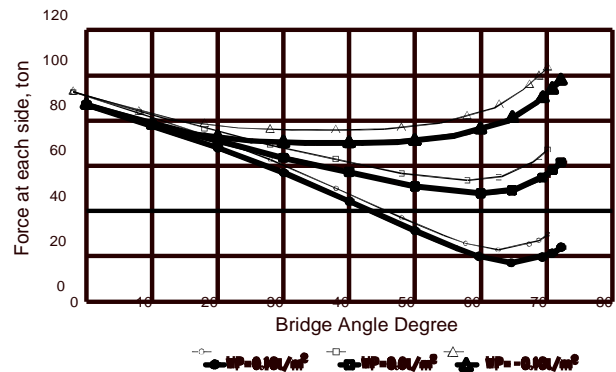


Figure 10: Hydraulic cylinder force per side (2 cylinders) vs. bridge angle at different wind loads

The system stability was maintained by avoiding the negative force resulted from the action of force reversing. The angles varied from close to open state; i.e., from 0 to 70 degrees. Figures 9, 10 show the variation of hydraulic cylinder forces and pressure, respectively versus the bridge angles at different directions of wind loads.

The pressure envelope ranges from 20 to 95 tons per side. The minimum positive 20 tons force adds safety against sudden high speed of wind. The selected hydraulic cylinder in accordance has a limit range from 30 to 150 bars, as recommended by the AASHTO. The percentage of wind load on the hydraulic cylinder at the open state with respect to the starting open state for both the positive and negative wind directions ranges from a reduction of 76.6% to an increase of 2.22%, respectively. While the effect on the hydraulic pressure varied from a reduction of 72.8% to an increase of 6.67%, respectively.

Figures 11, 12 show the variation of driving torque and column base moment, respectively versus the bridge angles at the different directions of wind loads. Under the different loading combinations, the envelope of driving torques and column base moment ranges from 25 to 140 m.t.

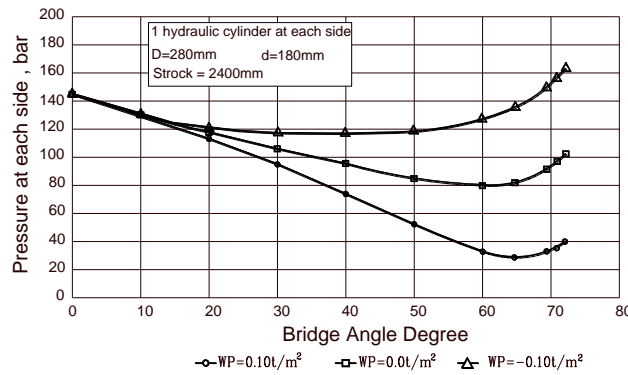


Figure 11: Hydraulic cylinder pressure vs. bridge angle at different wind loads.

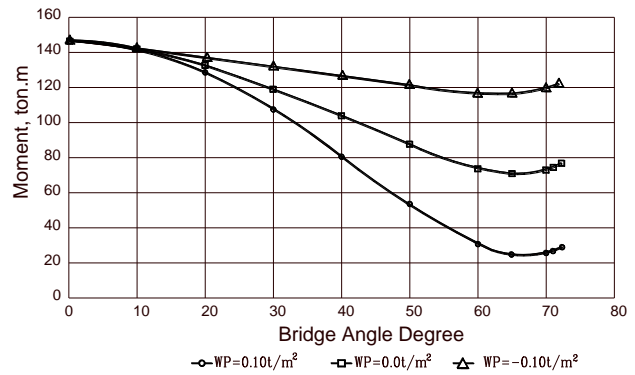


Figure 12: Hydraulic Column base moment vs. bridge angle at different wind loads.

The percentage of wind load effects on the driving torques and column base moment at the open state with respect to the starting open state for both the positive and negative wind directions range varied from a reduction of 82.14% and 14.28%, respectively.

It is worthy to note that the maximum design forces on the hydraulic cylinder is reached at the complete open  $[\theta = 70 \text{ degrees}]$ , while the maximum torques on driving units and moment on the supporting columns is reached at the start of open angles  $[\theta = 0.0 \text{ degree}]$ , with the opposite wind direction. These results are dictated from the exigency of maximum lifting arm at the start open angle.

Table 1: Reaction forces with the different analysis wind Load cases

	Case a	Case b	Case c
<b>Reaction Forces</b>			
Force in hydraulic cylinder each side [T]	57.84	21.81	93.87
Pressure in hydraulic cylinder each side[Bar]	93.93	35.41	152.4
Driving torque [T.m]	73.17	27.59	118.8



The limiting wind speed has been studied for different speed required to maintain the bridge components safely during open and close cases. This has been achieved with the imposing of different wind intensities to the bridge corresponding to different wind speeds. The parametric study showed that the bridge is safely open till a wind speed of 80 km/hour corresponding to wind intensity of 200 kg/m<sup>2</sup>.

## 7 Testing

The movable bridge bay has been subjected to different stages of inspection and tests. The inspection included the deck fabrications, erection, and electro-mechanical hydraulic devices installation. Tests included loading the bridge with two 30 tons trucks. The maximum measured deflection reached 9.30 mm with recovery percentage of 95 %, in addition to the cold test for the bay open. The cold test visualized the performance and balances between the bascule and lift span at the different open angles till to complete opening, Figure 13.



Figure 13: Cold test of Movable bridge bay

The performance of valves system has been checked. The valves system consists of the pressure relief valve, the check control valve, the flow control valve, the pressure switch valve and the throttling valves. The two pumps inject the oil to the main feeding lines through the check valves toward the flow valve. When the pressure is increased the relief valve is used to return the oil to the oil tank. The throttling valves are used to control the constant speed for the open and close. The constant speed is achieved by decreasing the feeding pressure of the hydraulic cylinder so that it reduces the speed and eliminates the effect of acceleration torque.

The filters with bypass has the capability to retain impurities up to 10 µm with absolute filtration for return line of 200 l/min at pressure 157 bar and 230 l/min at pressure 157 bar for the main feeding line.

The sensitivity limit switch and proximity switch to control the stroke of hydraulic cylinder have been checked through the sent signals to the main control room and the fulcrum.

The insulation resistance is checked with a Megger apparatus. The test required switching off and on the current to avoid electrical shock.

The cold test included also the inspection for the performance of the provided alternative operating system, represented by a complete hydraulic set equivalent to the original one but manually pumped, in case of electric power shut down.

## 8 Concluding Remarks

The basic engineering aspects of Port-Said movable bridge have been presented. From the preceding the prominent aspects of the project were:

In order for the bascule leaf to be properly aligned, key checks have been performed during and after erection. The principal causes of misalignment are derived from errors in machinery, inaccurate layout during construction and improper installation of racks, bearings, shafts, pinion gears and tread plates.

At last, steel bascule bridges are economical, compact and useful transportation structures if they are well designed and built, properly maintained and suitably aligned. In addition, they need to detailed inspection of material condition and structural configuration.

The project represents a good example of how functional and limited budget constrains can be taken into account in a movable bridge project. These constrains were considered starting from the concept design stage and extended up to the detailed drawing stage.

## 9 References

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