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Stabilization of Double Leaf Bascules

Stabilité des ponts à bascules

Zur Stabilisierung doppelter Klappbrücken

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SUMMARY

This paper describes the positive and negative aspects of selecting a double leaf bascule for a movable bridge application, and describes various defects that can be encountered in the load supporting system of double leaf bascules. Solutions to problems encountered in bascule bridges are outlined, as are ways of avoiding these problems.

RÉSUMÉ

L'article décrit les aspects positifs et négatifs de la sélection d'un pont à bascules doubles dans le cas d'un pont mobile et décrit divers défauts rencontrés dans le système de charges de ces ponts à bascules. Il présente les solutions aux problèmes rencontrés dans ce type de pont, ainsi que les possibilités d'éviter l'apparition de ces problèmes.

ZUSAMMENFASSUNG

Der Beitrag behandelt die Vor- und Nachteile bei der Ausgestaltung einer beweglichen Brücke als doppelte Klappbrücke und mögliche Schäden, die an den Klappenlagern auftreten können. Für diese Probleme werden Lösungen und vorbeugende Gegenmassnahmen erörtert.

1. INTRODUCTION

Most double leaf bascule bridges consist of two cantilever spans projected toward each other, connected at their tips by a suitable shear lock. They can open and close more quickly than other types of movable bridges, are less affected by wind loads than a single leaf bascule spanning the same channel width, and use slightly less structural steel than other types of movable bridges. Double leaf bascules are less susceptible to collision with vessels and are considered more aesthetically pleasing than other types of movable bridges. These advantages are balanced by complications, particularly in regard to stability of the structures under live load.

2. STABILIZATION

Double leaf bascule bridges frequently have problems with seating. The bridge may be carrying live loads larger than those designed for, overstressing the support system. The bridge stabilizing devices may have suffered deterioration so that they cannot contain the forces imposed on them. The bridge stabilizing devices may be improperly adjusted so that they do not perform their intended function. These devices include: live load shoes which form stops for each moving leaf as it attains its seated position; center or shear locks forming a vertical tie between the two leaves of a double leaf bascule bridge when in the closed position; live load anchors which are capable of exerting a downward force at the rear of the bridge counterweight; tail locks which form a shear connection at or near the rear of the bridge counterweight, and balance of the moving leaf.

2.1 Stabilizing Components

2.1.1 Live Load Supports

There are two common variations of basic live load support for double leaf bascule bridges:

- "Live Load Shoes" located under the bascule girder between trunnion or tracks and sea wall.

This type is used on most double leaf bascules because of the advantage in reducing the maximum trunnion or track loading. Live load shoes bolted to the bottom flange of the bascule girders make contact with castings anchored to the pier. This support is normally quite durable; the most common mode of deterioration is corrosion when debris is allowed to build up around the castings.

- "Live Load Anchorages" near the rear of the counterweights.

This type allows constructing a smaller pier, as the center of rotation can be placed close to the sea wall. The live load moment is taken to the pier near the rear of the counterweight. This requires a large superstructure element to act as a tiedown for the rear of the leaf, usually in conjunction with an approach roadway deck. Rear live load anchorages have the disadvantage of producing higher trunnion loads and span moments. They tend to be less accessible than forward live load shoes, and are thus more prone to maladjustment.

2.1.2 Anchors

Live load anchors are sometimes used in combination with forward live load shoes but are set up so that they have small clearances when the main live load shoes are firmly seated. As load is released at the trunnion columns, due to live load on the cantilever arm shifting the center of gravity toward the live load shoes, the anchors should come into contact. It is almost impossible to adjust these components precisely, so the anchors usually do no work until the main live load shoes become worn, when the anchors end up taking over the main live load support and become susceptible to structural failure.

2.1.3 Center Locks

Toe end support consists of shear center locks which transmit vertical loading to the toe of the mating leaf. When a live load is near the middle of the bridge, the center locks provide for the two leaves to share this load, forcing them to have equal deflection. After the center locks wear excessively, the equalization of deflection is lost, and the two leaves bounce as each live load passes from one leaf to the other. A new bridge with center locks properly aligned and adjusted to the design clearances may develop excessive vertical play within a year or two of being opened to traffic.

Trunnion bascules generally use retractible lock bars. The retractible lock bars slide in guides and sockets, which are lubricated to minimize wear. The lubricant attracts grit, which makes it a very effective abrasive compound, wearing away the bar and guide shoe material with every actuation of the lock mechanism, and abrading the bar and socket every time live load causes the span to deflect. Once the clearance at these components has been increased by abrasive wear, impacts at the bearing surfaces from live load add to the rate of increase of the clearance by plastically deforming the shoe and/or bar material.

2.1.4 Tail Locks

Tail locks are used most often when a part of the roadway deck is behind the rotational center of the moving leaf, to provide live load support at the rear of the leaf, forming a shear connection at the rear of the counterweight.

Tail locks usually have no provision for adjustment so they are unlikely to carry any live load reaction, even when newly installed. Tail locks are usually very difficult to reach for maintenance or inspection, and they are consequently usually very worn and out of alignment. Tail locks have frequently been damaged due to actuation when the bridge was not fully closed.

2.1.5 Alignment

Difficulty frequently arises in obtaining proper alignment and effective operation of all span support and stabilization devices. It is a difficult task to achieve proper initial alignment at construction. In-service wear and occasional overloads can cause misalignment of these bridge components even when properly erected. A double leaf bascule bridge with two main girders at each leaf may have as many as eighteen points of support:

- Four trunnions or tracks
- Four live load shoes
- Four live load anchors
- Four tail locks
- Two center locks

2.2 Superstructure

The double leaf bascule superstructure is an important factor in the stability of the bridge. Flexible leaves will deflect more under a given live load than rigid ones, storing more energy as they are bent like a spring under live load. When the live load moves off, the leaf springs back up, imputing a negative impact on the leaf and possibly causing it to lift off its live load supports. For this reason, bridges carrying heavy high speed traffic should be built much stiffer and heavier than bridges carrying light, slow traffic. The bridge should also be carefully designed and constructed to avoid abrupt changes in roadway profile, particularly at the joint between the leaves, as these add to impact forces.

Lifting off under live load and impacting upon the live load supports causes damage to all components, particularly the machinery. The damage is most readily apparent in excessive wear at the rack and pinion teeth, but may also show up as wear at the trunnions or tracks. In more unusual cases wear or damage may show up at other drive components, or on the bridge superstructure or substructure. Frequently, damage is readily apparent at the live load shoes, anchors, and other stabilizing components.

3. BALANCE OF BASCULE BRIDGES

Stability is highly dependent on the balance of the span. It should be slightly "span heavy" when closed, which means that its center of gravity should be toward the navigation channel from the rotating center, when closed to marine traffic. This produces a slight positive dead load reaction at the live load bearings.

Bascule bridges consist of a large moving mass of superstructure, deck, and counterweight, which can be considered balanced for structural purposes. The span can be considered essentially rigid as it rotates between opened and closed positions. This applies whether it is a simple trunnion leaf, a rolling lift, or an articulated counterweight type. The counterweight gravitational moment is always in a fixed position relative to the bascule span due to the parallelogram arrangement of the pivot points. An exception to this rule is a bascule with operating struts as they move in a different path than the superstructure. The operating strut could be heavy enough to have a noticeable effect on the balance, but this usually only happens with single leaf railroad bridges.

It can be very difficult to achieve a correct balance state, as the amount of imbalance, measured as force at the live load shoes, should be less than 1% of the dead weight. If a bascule bridge leaf had zero imbalance, the machinery would not have to overcome any gravitational loadings while opening or closing the span. The correct balance condition increases the amount of power required to open the leaf because the leaf is actually made to be in a state of unbalance. Opening the span requires lifting the center of gravity through the arc it traverses from the closed to open position. This extra power is a small fraction of the operating cost of a bridge, and the extra machinery strength required is negligible compared to other loadings which should be considered in design.

3.1 Vector Analysis

The position of the center of gravity of the moving leaf can be located so that the span heavy unbalance is at a maximum when the leaf is seated, decreases to zero as the leaf opens, and assumes a negative, "counterweight heavy", condition as the span reaches the open position. This ideal condition of balance provides stable seating in the closed position for live load. It also stabilizes the span in the open position so that a drop of the open leaf would be prevented should there be a mechanical or electrical failure. The ideal condition of balance is illustrated in Figure 1.

The vector "r" from the axis of rotation to the center of gravity should be small, to avoid excessive impact forces on seating, and to minimize power requirements. Hool and Kinne, in "Movable and Long Span Steel Bridges", recommend that the horizontal distance from the axis of rotation to the center of gravity should be just enough to cause a moment sufficient to turn the leaf against friction. The friction factor, k, ranges from 15 percent of

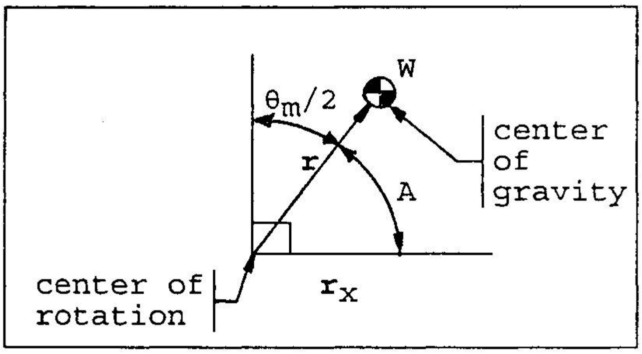

FIGURE 1 - Vector

the total weight of the moving span for a trunnion bascule with friction bearings to 0.9 percent for a rolling lift bridge. These numbers are based on heavy truss type bascule bridges. More flexible leaves, or very low friction trunnions, require the amount of imbalance to be increased somewhat. The friction moment is Wr_tk and this is equated to the span weight times the horizontal component of the vector to the center of gravity, when the leaf is closed ($\theta = 0$).

$$Wr_x = Wr_tk \qquad \text{Eq (1)}$$

- W = weight of the moving leaf
- r = vector from the axis of rotation to the center of gravity of the moving leaf
- r_x = horizontal component of vector r
- r_t = radius of the bascule trunnion or rolling lift curved tracks
- k = coefficient of friction; 0.15 for friction trunnions, 0.009 for rolling lift or roller bearing trunnion friction
- A = angle between r and r_x

θ = opening angle
θ_m = maximum opening angle

For bascule bridges with bronze-journaled trunnions in the 250 to 750 mm diameter range, the distance "r_x", of the horizontal component of "r" would range from 2.25 to 112.5 mm. For rolling lift bridges with curved track radii of 8 meters, the distance, "r_x", would be 72 mm.

The angle "A", should be chosen so that the maximum opening angle, θ_m, is equally divided about the vertical axis.

$$A = 90 - (\theta_m/2) \qquad \text{Eq (2)}$$

This will minimize work and wear of the operating machinery during a complete operating cycle while accomplishing the desired gravitational stabilization. The horizontal component, "r_x", with the leaf closed ($\theta = 0$), determines the gravitational seating force at the live load shoes. "r_x" equals 0.15 times the trunnion radius or 0.009 times the curved track radius, as in equation (1) and equals "r" times the cosine of "A" when $\theta = 0$.

$$Wr_x = Wr_tk = Wr\cos(A+\theta) \qquad \text{Eq (3)}$$

3.2 Balancing

The desired position of the center of gravity should be determined when designing a new bridge. The condition is difficult to achieve due to construction variations, accommodated by pockets in the counterweights where small weights can be added, removed or shifted. The pockets are usually located so that longitudinal and vertical adjustments in the center of gravity can be made. Lateral balance is difficult to measure and does not have as profound an effect on operation.

Not all designers have agreed on the ideal balance condition, resulting in a wide variation in existing bridge balance conditions. Redecking, strengthening, removing overhead trolley wires and supports, painting, moisture absorption and build up of debris can significantly affect the balance condition. The balance condition should be ideal to reduce power requirements and machinery wear and assure safe and reliable operation. Adjustment of the balance condition of existing bridges has frequently involved placements of weights with test openings of the bridge until an acceptable condition of balance was reached. Trial and error methods entail considerable time and expense while never assuring that the balance condition is actually known.

Vector analysis can be used to accurately balance a bascule leaf about the rotational axis. The existing span imbalance vector Wr_i, can be determined by measuring and recording the operating torque at the rack pinion shafts as the bridge is opened and closed under controlled conditions of no wind, snow or ice.

With the initial values of "Wr_i" obtained, and the desired final imbalance value of "Wr_f" assumed, vector analysis can be used to determine the required weight shift (see Figure 2):

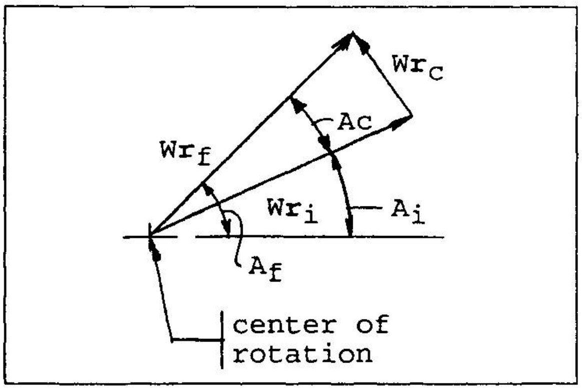

FIGURE 2 - Correction Vector

The correction vector "Wr_c" can be accomplished by shifting small movable weights from the lower to the upper counterweight pockets as shown in Figure 3:

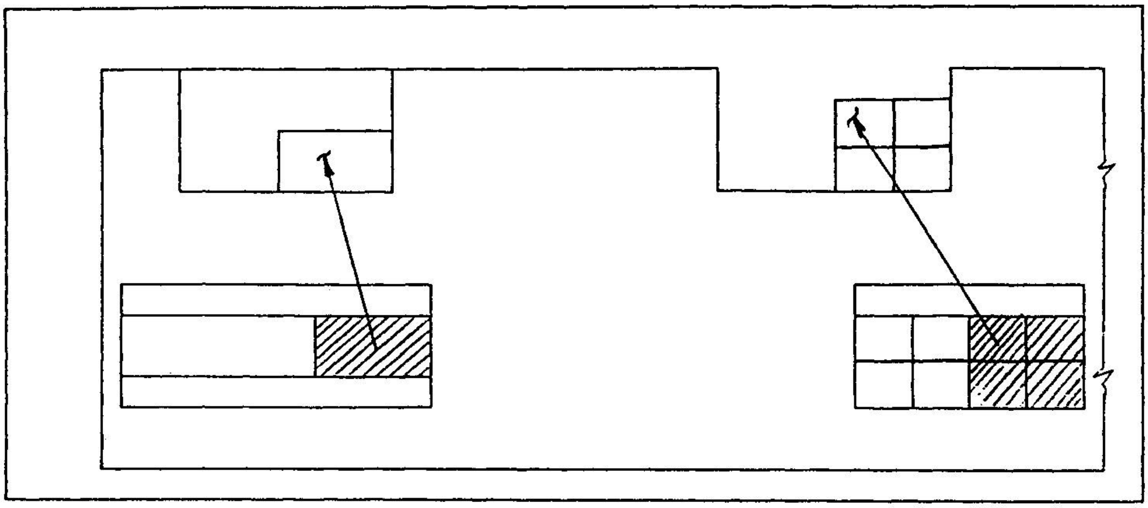

FIGURE 3 - Vertical Section at Counterweight Parallel to Roadway

Many bridges require the addition of weight on the tip of the cantilever arm in order to properly locate the center of gravity.

Friction is canceled out, assuming it is constant, so that the imbalance torques at the rack pinion shafts can be readily derived:

$$(Tup + Tdn)/2 = Wr \cos (A + \theta) \qquad \text{Eq (4)}$$

where: Tup = torques to open
Tdn = torque to close
θ = opening angle at measurement

4. CONCLUSIONS AND RECOMMENDATIONS

Double leaf bascule bridges become unstable because they are poorly designed, poorly constructed, or poorly maintained. They are more susceptible to deficiencies from these causes because they are more delicate than other types of movable bridges.

- Properly designed double leaf bascule bridge should be very rigid.
- The leaves of the double leaf bascule should be firmly supported on very solid live load shoes located adjacent to the pier sea wall, far from the center of rotation.
- The balance of the double leaf bascule should be such that a dead load reaction exists on the live load shoes when the bridge is closed, that is in excess of any negative reaction from live load.
- The roadway surfaces on the double leaf bascule should be formed so that there is no misalignment at the joints, either at the heels of the leaves or at the toes. The vertical curve should be continuous from one leaf to the other and from each leaf to its approach.
- Center locks should minimize the difference in vertical deflection of the tips of the leaves under live load. They should have little or no clearance for free vertical displacement, while allowing longitudinal and rotational displacement due to thermal, live load or other effects.