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"Rehabilitation of the Hanover Street over the Patapsco River"

A. The Rall Bascule

In his epochal 1925 treatise on bridge engineering, J.A.L. Waddell states that:

> "The modern era of bascule building may properly be said to have commenced with the construction of the Tower Bridge of London in 1894. At the same time the Scherzer rolling lift bascule was completed for the Metropolitan Elevated Railroad over the Chicago River...."
>
> "The advantages of the bascule over the swing span are:
>
> 1. Wide centre channel free from piers and pier protection.
> 2. Increased space for dockage.
> 3. Rapidity of opening to permit passage of vessels and subsequent closing again for bridge traffic."

During the next two decades, the number of bascule span types proliferated, each patented by individual designers or fabricators. The bascule bridge designs thus followed the common practice of American bridge engineering, prior to World War I of combining the roles of bridge designer, fabricator and erector into a single "bridge company". After WWI the more modern practice of separating the designer from the fabricator/erector led to a gradual disappearance of multiple bascule span types, so that by WWII the trunnion bascule was the almost universal choice, although Hool and Kinne present the Rall type in their 1943 2nd Edition of "Movable and Long-Span Steel Bridges".

The rolling lift type of bascule bridge consists of two major types, the Scherzer and the Rall. As noted in the opening quote, the first Scherzer was built in 1894. The Theodore Rall patent was first issued in 1901 and re-issued in 1906 (see attached copy). By the time of the construction of the Hanover Street Bridge in 1913, the Rall patent was apparently owned by the Strobel Steel Construction Co. of Chicago, IL who continued to actively promote the type.

The basis of the Rall patent and the chief characteristic of this bridge type is that the trunnion of the span is installed in a large steel roller, or wheel, which recedes from the channel opening as the span is rotated upward. The rotation of the span is driven by a swing strut which describes an arc through which the span rotates and translates. The arc of the swing strut was cleverly conceived to lift the roller/trunnion off of the track girder in the fully closed (down) position. Thus it was not subject to vehicular live load which would help to reduce wear on the bushing within the trunnion journal. A separate bearing shoe was provided to support the bascule span in the fully closed position.

The advantages of the Rall system were described by Waddell as providing the maximum clear channel opening for the minimum span (leaf) length. Also, the ability to remove the trunnion roller for maintenance was seen as an advantage over a fixed trunnion bascule. The disadvantages quoted by both Waddell and Hool and Kinne are those of a shifting load on the foundation. It would seem to the author that the added complexity of the system, and the necessity of an extremely large roller support girder would negate the span clearance cost advantage.

B. <u>Hanover Street Bridge</u>

Rall's patent shows two different applications of the basic concept: One is for a bascule girder and the other is for a thru truss bascule. The Hanover Street Bridge is an adaptation of the bascule girder type. The bridge crosses the Middle Branch of the Patapsco River and was built and is owned by the City of Baltimore. The bridge for many years was the primary north-south access to the City from South Baltimore and Annapolis. The Middle Branch of the Patapsco River is not a major harbor but does provide access to several industries and marinas. The bridge appears as a concrete arch structure with a center bascule span but the approaches are actually encased, three hinge steel truss arches. The total structure length is 2,290 feet, and it currently carries five lanes of heavy city traffic with a high percentage of trucks.

The bridge, as originally constructed in 1913-16, carried a 50' cartway with two trolley tracks. The bascule spans were originally provided with wooden decks, later replaced with a steel grid. The bridge deck was widened from four to five lanes in 1971 which involved extensive modification of the bascule leaves.

The two-leaf Rall rolling bascules span 161'-6" between live load bearings in the closed position. The overall length of each leaf is 99'-1⅜" out-to-out of deck. The out-to-out width of deck is 69'-0", consisting of a 60'-0" roadway and two sidewalks. The width of the bascule deck narrows to 48'-8" over the machinery houses with the remaining width supported on encased stringers spanning between the walls of the piers. The deck consists of 5" steel open grid in the full-width areas and a 5" concrete-filled grid in the narrow section over the operating machinery.

The deck was supported by twelve stringer lines between the girder lines for the full-length of each leaf. The stringer spacings vary. The four central lines of stringers consist of spaced, double channels which were the original trolley stringers from 1916. The remaining stringers were replaced in the 1971 rehabilitation and are either rolled steel "W" sections or double channels welded back-to-back. The stringers are continuous. An additional stringer line is mounted directly on the top flange of the main bascule girders, and there are two stringer lines supported on overhang brackets beyond the girders. These stringers extend only to the break line at the machinery houses where an intermediate bracket is provided.

The stringers are supported on seven floorbeams in each leaf. The four heel-most floorbeams (4, 5, 6 and 7) are Warren Trusses built-up from riveted steel angles. The top chords of each truss consist of spaced double channels. The stringers are supported by "H" section risers mounted on the top chords. The stringers are not located at the panel points and, as such, introduce bending as well as compression in the top chords.

The three toe-most floorbeams (1, 2 and 3) are plate girders made of a riveted web plate with angle flanges. There are no coverplates.

The overhang brackets are located at the floorbeams and consist of original flared, riveted brackets to which a "W" section was fitted and welded on top in 1971 to strengthen the brackets for live load. These tie beams are welded to the top of the main girders and extend to the first interior stringer line.

The two main girders in each leaf are spaced at 47'-10¾" centers and consist of four truss bays toward the heel and two box girder bays towards the toe. The live load bearings and trunnion/roller are located at Floorbeam 6. The truss and girder sections are built-up from riveted steel angles and plates. In 1971, additional steel angles were welded to some sections. The fixed concrete counterweight is cantilevered beyond the heel floorbeam. The flanking spans cantilever over the backwall of the piers.

In 1982, the City replaced the original manual controls with a computerized motor Control Center which was to provide "one button" control of the span raising and lowering.

In 1988, the City hired Kidde Consultants, Inc. (now KCI) to inspect and design the rehabilitation of the bridge. A.G. Lichtenstein & Associates, Inc. was retained by KCI to perform the mechanical and structural inspections and rehabilitation plans for the bascule spans. Because of the 1982 installation of the new control center, no electrical inspection or rehabilitation was included in the contract.

A.G. Lichtenstein & Associates, Inc. performed a structural and mechanical inspection in November, 1988. Our inspection revealed that the bascule spans had suffered from extensive fatigue cracking in the grid deck and roadway stringers. The floorbeams, stringer supports, and lateral bracing had extensive areas of loss and hole thru due to corrosion. Our analysis indicated that the floorbeams were somewhat overstressed due to live load. In addition, the extensive welding done to the floorbeams and girders in 1971 had introduced many Category E and E' fatigue details which would have a limited fatigue life.

Mechanically, the bridge had several areas of concern:

- The northwest swing strut pin at the live load shoe was frozen in its bushing.

- The open differential gears were worn and poorly lubricated due to difficult access.

- The northwest operating strut pin was severely worn and vibrated during span operation.

- The toe locks on the north leaf which had been replaced in 1971 were so badly worn that the two leaves were essentially acting as cantilevers. The toe lock drive machinery was located in the north span machinery room and was connected to the locks by a series of gears and rods. In addition, access for maintenance of the toe locks was by an access hatch in the roadway.

A.G. Lichtenstein & Associates, Inc. recommended and designed a program of rehabilitation for the bascule span to include:

- Replacement of the grid deck and stringers.

- Strengthening of the floorbeams.

- Removal of fatigue details from the floorbeams and girders.

- Modifying the girder-type floorbeams to provide catwalk openings and a catwalk to allow access to the toe lock areas for inspection and maintenance.

- Replacement of the lateral bracing in its entirety and other steel repairs throughout.

Mechanically, our recommendations included:

- Replacement of the operating strut pins.

- Replacement of the NW swing strut pins.

- Replacement of the open differential with an enclosed differential drive unit.

- Install an electric clutch to switch between the emergency and main drive motors.

- Replace span brake with a thruster-type brake.

- Replace the toe locks and drive mechanisms in their entirety with self-contained lock drives located at the tip of the bascule girders.

C. Special Design Considerations

The Hanover Street Bridge provides an essential link between the industrial port areas of Locust Point and Brooklyn within the City. In addition, the Harbor Hospital Center on the south end of the bridge is the major emergency hospital for the entire south Baltimore area. It was essential, therefore, that traffic be maintained across the bridge to the extent possible. Additionally, the City made it a condition of the contract that both leaves remain operable throughout construction. Since the removal of the deck and stringers would unbalance the leaves, and the removal and replacement of operating machinery and pins would render the spans unmovable, we held considerable discussions with the City, FHWA and the USCG as to what disruptions would be acceptable. The traffic control patterns also had to conform with the reconstruction of several of the north approach spans which KCI was designing.

The final plan was for the staging of construction to allow 3 lanes of traffic during the morning and afternoon "peaks", 2 in the peak direction and one in the reverse direction. Off peak, the contractor could close an additional lane for access, equipment, etc. A total of 3 stages of construction were proposed (see sketch) with the deck panels and new stringer locations laid out so as to allow the deck and stringers to be prefabricated into panels of a size easily handled by rubber-tired cranes. We determined that the welding of the deck to the stringers was the critical path in installing the deck so that preassembling the deck to the stringers significantly reduced the time required to install the deck in the field, and also would provide better quality deck welds.

It was necessary to install "Jersey" barriers between the open deck and traffic if the work was to proceed with traffic maintained. The presence of the barriers would, however, render the bridge inoperable. The contractor was, therefore, given one of two options for installing the deck panels:

1) With the USCG's permission, the channel could be closed to navigation on weekends, such that barriers could be installed and the deck replaced. A stiff hourly liquidated damages would be assessed on Monday mornings if the bridge was not returned to operability and 3 lanes of traffic restored.

or 2) The contractor was to be allowed 6 weekends of total outages (traffic and navigation) for other work (see below). He could install the deck panels during those closures as he saw fit.

It turns out that the contractor chose to install all of the deck panels during two, weekend total closures. In either case, it was required that the deck panels be permanently attached and the leaves temporarily balanced before the bridge would be allowed to operate.

The major items of mechanical work; toe locks, differentials, live load pins and operating strut pins all would require the leaf under construction to be inoperable while the work was performed. AGLAS researched the time necessary to perform each operation and determined that, with proper preparation, the contractor could perform any or all of the necessary steps in a non-stop, 56 hour period from 9:00 p.m., Friday to 5:00 a.m., Monday. The critical operation would be pushing out the pins from the bushings, installing the new bushings, final machining of bushings and driving the new pins home.

AGLAS determined that 6 weekends would be required to perform the work on both leaves (only one leaf could be rendered inoperable at a time), and also to perform the final leaf balancing at the conclusion of the contract.

Since the total closure of the bridge to traffic was deemed highly undesirable, AGLAS developed an incentive/disincentive specification which rewarded the contractor for using less than the six allowed outages and penalized him for exceeding that number.

The balance of the leaves had been altered over the years by the City maintenance crews to make the leaves considerably toe-heavy. They believed the toe-heavy condition was necessary due to the deteriorated toe locks to ensure that the leaves didn't jump-up under live load passage. This amount of toe-heaviness caused extreme wear on the gears and required motor-braking throughout the lowering operation.

Our specifications required the contractor to perform an initial balance prior to beginning work to bring both leaves within an out-of-balance of not more than 80,000 ft-lbs. The contractor was required to maintain this initial balance condition throughout construction by installing or removing counterweight blocks. Our design provided for new counterweight trays on the heel and toe of the leaves. The contractor chose to perform the initial balance by strain gauging the drive shafts. After initial balance, load cells were installed at the heel stops to measure the change in fully-lowered balance. At the completion of the contract, the bridge will be finally balanced to a range of 40,000 ft-lbs to 80,000 ft-lbs toe heavy.

The other structural and mechanical work was to be performed from below without traffic disruption. The contractor was allowed to moor a barge in the channel so that he could use a small crane and "JLG"-type manlifts to perform most of the structural steel repairs.

D. Construction Experiences

The final plans were submitted in December, 1989 and the bids were opened May 16, 1990. The successful low bidder was Cianbro Corporation of Pittsfield, ME. The bascule span (mechanical and structural) portion of the bid items totaled $2,912,050 versus our E.E. of $2,774,840, or 4.9% over our estimate.

AGLAS, through KCI, was retained to perform shop drawing and construction consultation services. During construction, several major "surprises" occurred which have delayed completion of the bascule span work beyond the submission date of this paper.

Mechanically, this has included the freezing of a bushing on the west operating strut of the north leaf, which rendered that leaf almost unusable. This problem would have required dismantling the operating drive gearing after the new deck was already installed. AGLAS provided a cost effective solution of drilling through the journal housing to re-dowel the bushing to the journal and re-open the grease fittings. So far, this has proved a successful retrofit.

At the contractor's suggestion, the City agreed to have the main trunnion (wheel hub) fittings disassembled for inspection. The bushings/shaft clearances showed signs of excessive wear. The City agreed to expand the scope of the contract to have Cianbro remove all 4 wheels and the track castings they roll on, to replace the bushings and restore the rolling surfaces which had become rounded due to wear and debris build-up. To remove the wheels, the walls of the machinery house facing the channel had to be dismantled and a supporting framework constructed in each of the 4 houses (one leaf at a time). The wheels were jacked sideways off the trunnion shafts, hung from a series of Hillman rollers and rolled out clear of the machinery houses where they could be "picked" by the barge-mounted crane. This is hardly the "ease of repair" the designers mentioned as an advantage of this type.

Once removed to the machine shop, a series of defects were noted in the inner bore of the wheels. Ultrasound testing initially showed these to be cracks extending into the hub wall! It appeared that the wheels might have to be recast. At AGLAS' urging, the City took 1"ϕ cores, 1½" deep through one of these "cracks" and had them examined by a metallurgical lab, which reported them to be cooling lines from the original casting process. The "cracks" have been repaired by welding and the wheels are being reinstalled at the time of this writing.

The original track castings had suffered from extreme "plastic flow" along the edges and were badly distorted. The contractor is refabricating the castings from A36 plate steel with an A709 Grade 70 top rolling plate, which is required by AASHTO for "linear bearing" of a roller and rolling plate.

The other significant issue which has continued throughout construction was the City's original decision <u>not</u> to include an inspection and repair of the electrical operating circuitry. All of the new equipment installed require operating power and limit switches showing operating positions. With a Motor Control Center with Programmed Logic Controls operating the bridge, it should have been apparent that significant changes in the MCC and the operating instructions would be required. Although AGLAS was able to provide the City with the Electrical Engineering required for this work, it has all been "after the fact" and, as such, has inevitably delayed the project.

E. Conclusions

The Hanover Street Bridge is an important surviving example of a bascule bridge type no longer constructed. The Rall design is an example of the kind of innovative thinking which is lacking in today's conservative bridge engineering environment. As such, the City of Baltimore should be congratulated for its decision to restore the bridge.

The problems encountered during the construction phase show the pressing need for the designer to remain involved throughout the construction phase. Inevitably, with rehabilitation of 80-year-old bridges of this complexity, problems will be uncovered during disassembly, cleaning, etc. that could not have been apparent prior to construction. The designer, working with the owner and contractor can minimize the cost impacts of these discoveries to the client due to his understanding of the overall design.

We believe that the Hanover Street Bridge will be able to "keep on rolling" many years into the future.