Milwaukee's New Knapp Street Towerless Vertical Lift Bridge

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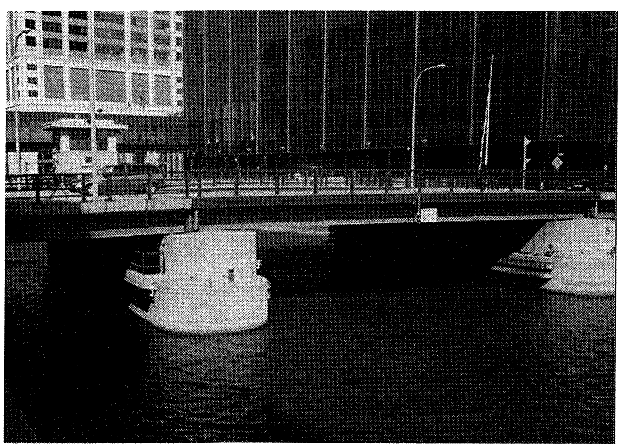
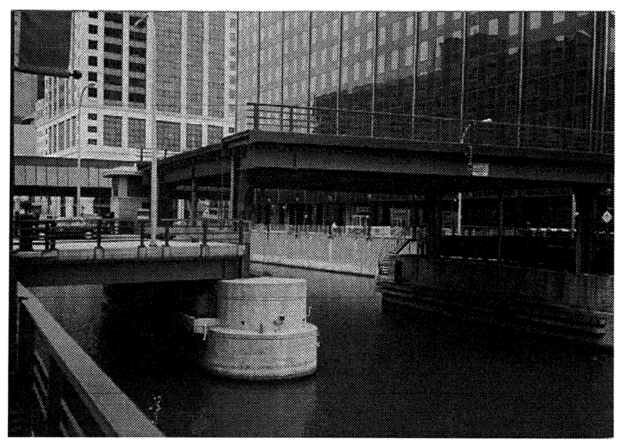
Combination of Advantages

Of the three major types of movable bridges, vertical lift bridges tend to be associated with the widest channels, allowing passage of the largest ships. Aesthetics usually take a back seat to function in the case of most vertical lift bridges.

Where the required width of channel allows, and aesthetics can be of higher priority, bascule bridges are preferred in most applications. In addition to meeting the functional requirements, the use of solid fascia girders and hidden machinery with under-slung counterweights typically provides an aesthetically pleasing appearance.

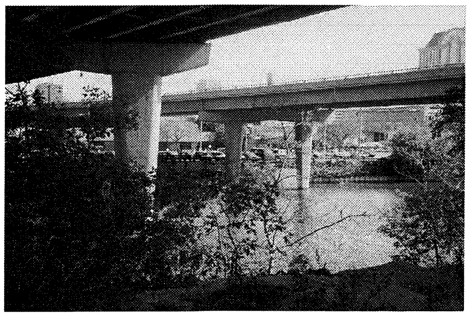
While bascule bridges can be both beautiful and functional for channels of limited width, they still have their pros and cons. Single leaf bascules provide a natural roadway barrier to the channel from one side only when the leaf is raised, while the other side requires an additional barrier to prevent vehicles from entering the open draw. Double leaf bascules usually provide a natural blocking of the roadway from both sides, but require precise alignment of the leaves to allow locking at the center of the span.



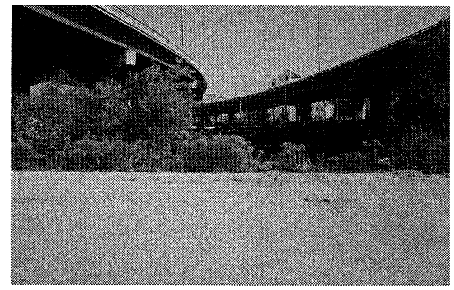


As described in George Roemer's paper, entitled *That's a Vertical Lift – Where are the Towers?* (also presented at this Symposium), the City of Milwaukee developed the towerless type of vertical lift bridge in the late 1960's. This type of structure combines selected advantages of both types of bridges in locations where requirements for raised vertical clearances are limited. The clean lines associated with a girder-type bascule are combined with the simplicity associated with a single movable span and the lower costs of hydraulic operation. Blocking of the roadways on both sides of the channel is also accomplished without additional powered mechanisms.

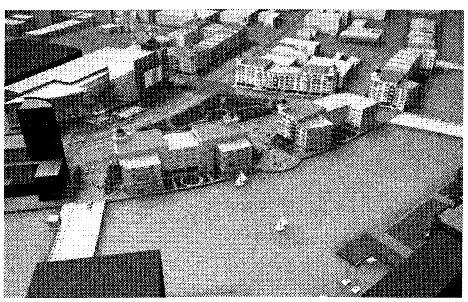
The Project



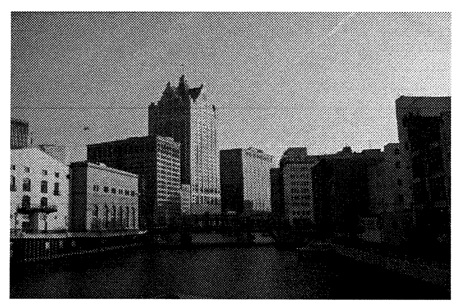
The Park East Freeway was originally designed to cross the north side of Milwaukee to connect northbound and southbound I-43 with the Lake Michigan shore. Here, the freeway would turn south and connect with another expressway in the harbor area. The plan was to surround Milwaukee with elevated freeways. The Park East Freeway was already partially constructed in the early 1970's when public outcry and new political leadership developed into a "freeway revolt", particularly against the proposed structure that would impact the city's lakefront. The plan to extend the Park East Freeway was then abandoned.

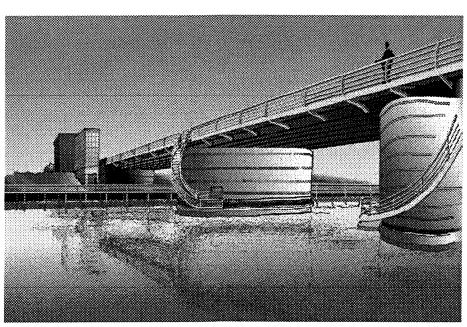


At that point, the Park East extended eastward only across the south flowing Milwaukee River, to provide a means of entering the downtown area from the north and west. Since it was never extended to the lakefront to the east, the freeway's 6 lanes have always been under-utilized, and the elevated structure has been considered an eyesore by many of the city's inhabitants. The freeway also tends to detrimentally separate the thriving downtown area from the less prosperous north side of the city.



In late 1999 an area redevelopment plan was approved. This plan centers around the removal of the Park East Freeway, the proposed Harley Davidson Museum and other new construction, the extensions of decorative and functional riverwalks on both sides of the river, and restoration of historic structures in the area. The Park East Freeway removal restores 26 acres of prime land to available use, and is expected to yield more than $250 million of new investment. New condominiums and other residential developments are planned. Businesses on the north side of the City anticipate a large increase in revenue. A new six lane boulevard and new river crossing will be provided. This crossing will be the eighth of Milwaukee's towerless vertical lift bridges.





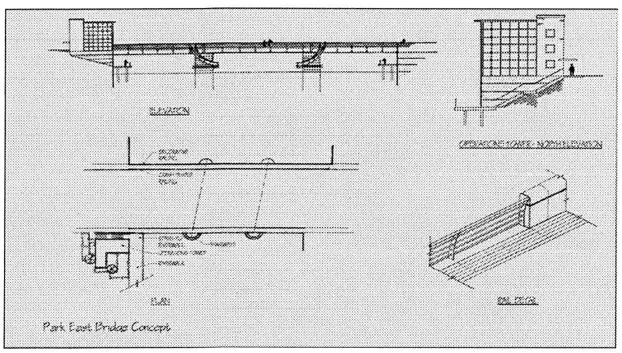
After the area redevelopment study was completed, HNTB Corporation was retained to develop preliminary plans for the new traffic corridor. Shortly thereafter, HNTB was given the responsibility for final design of both the roadway and the bridge. This paper discusses the design of Milwaukee's newest towerless vertical lift bridge, shown conceptually at left.

The Commitment

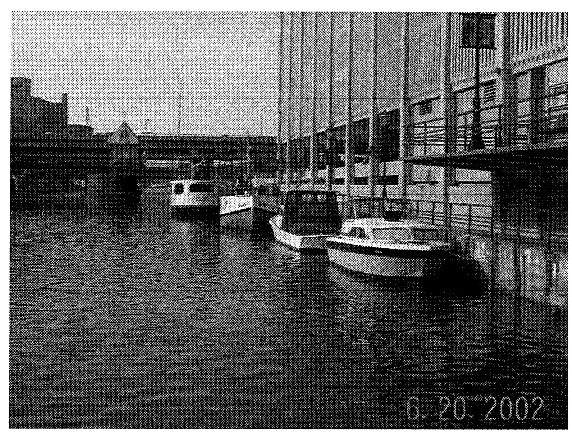
Just like a consistent hitter in baseball, HNTB's goal in every project is to "go 4 for 4": to produce a quality design, on time, within budget, and to the client's satisfaction. To do this, specific objectives for this project would include the following:

- Provide a functional and low cost structure that will also be aesthetically pleasing, in the tradition of the City's existing bridges.
- Meet the City's desire to make this bridge even more attractive, and to blend in with area.
- Address dimensional constraints that limit clearances.
- Meet recently implemented code requirements not in force when other City bridges were built, including those of AASHTO, OSHA, ADA, and the Wisconsin Energy Code.
- Improve operational performance beyond that of typical existing bridges.
- Meet a fast-track schedule of 6 months for final design and 17 months for construction.

The Design



Conceptual. HNTB's preliminary plans and study developed the connection of the existing terminations of McKinley Street on the west and Knapp Street on the east. The new bridge will be a skewed structure to accommodate the needs of the roadway and the existing curve in the Milwaukee River. The bridge will carry traffic over a 50'-6" clear channel. Short approaches will span from the abutments to each of the two lift span piers.

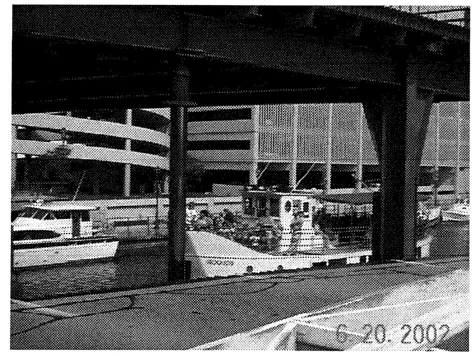


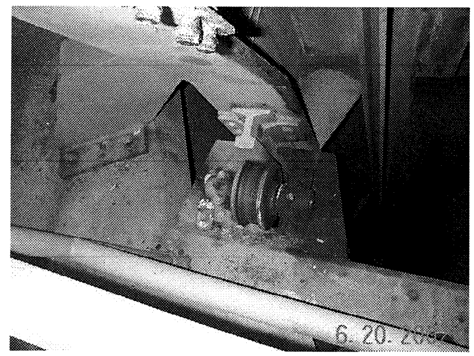
Sidewalks on both sides of the bridge will carry moderate to heavy pedestrian traffic during the day. They will tie into the nearby riverwalks that will be extended under the plan. At night, the bridge will be illuminated to provide light for pedestrians enjoying the local food and drink establishments nearby, and to enhance the appearance of the bridge above the river.

The navigation channel carries mostly pleasure craft from marinas upstream, plus a small amount of commercial traffic. The lifting height of the movable span will need to be adequate to provide 28'-6" vertical clearance when raised, which is the requirement for the river.

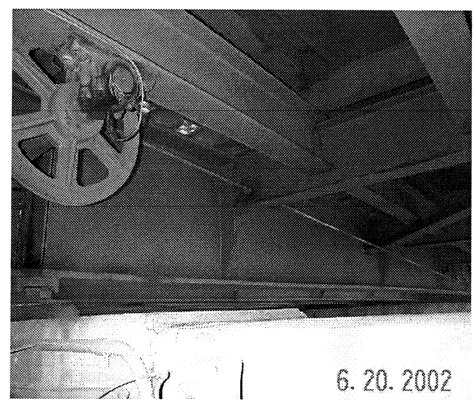
Previously Developed Concepts. To retain and possibly improve the worthwhile concepts associated with past bridges, plans for the previously constructed Michigan Street (1977) and Wells Street (1983) Bridges were given to HNTB so that they could be used for reference. The photos of these details, shown with this text, are from existing Milwaukee vertical lift bridges:

- Rigidly framed steel lifting structure, with a lifting girder at each end and two lifting legs at each end, plus rigid framing throughout. The rigidity of the structure allows it to raise and lower evenly with the assistance of mechanical equalizer systems. These equalizer systems will be described later.
- Lifting legs. The lift span is guided at each corner by a lifting leg, with each leg framing into the end of one of the lifting girders. The lifting legs are guided by pier mounted rollers that engage vertical crane rails attached to the legs. Thermal expansion of the span is accommodated by the use of plain, flange-less rollers at one pier, while longitudinal span drift is prevented by means of flanged rollers at the opposite pier. In addition to being used to guide the span, the lifting legs also include counterweight rope attachments, longitudinal and transverse equalizer rope attachments, and vertical rails to engage caliper brake units.





- Concealed counterweights. High density concrete is used to construct the concealed counterweights, located below the roadway within the piers, to keep the span in relative balance. The span is kept heavier than the total weight of the two counterweights in order for the span to be able to lower using the force of gravity alone. The amount of unbalance must be able to overcome the AASHTO-specified wind load of 2.5 psf normal to the deck when lowering, and must also overcome friction, rope bending, and the amount of inertial load experienced based on the required acceleration rate. It must also overcome all pressure drop associated with the hydraulic system.

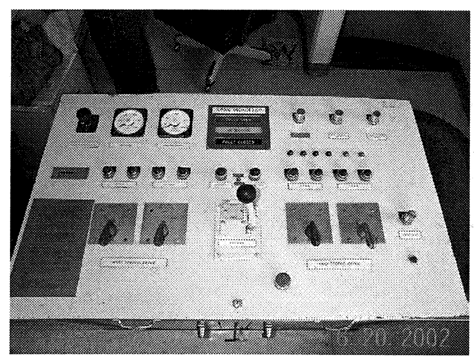


- Mechanical equalizer systems. A system of wire ropes and sheaves is used on each side and at each end of the lift span to keep the span level without skewing as it raises and lowers. As the span raises, the ropes pass over a system of deflector sheaves to lengthen or shorten corresponding rope ends equally, as required to evenly raise and lower each corner of the span. The tension in the ropes prevents any corner from lagging the others as the span raises or lowers. If a corner of the span would tend to lag the others, thereby tending to produce uneven lifting, the ropes at that corner will prevent this from occurring.

- Hydraulic system and jacking cylinders. A hydraulic system with one main and one auxiliary electric motor and hydraulic pump is used to operate the jacking cylinders, one at each pier in the case of smaller bridges such as Michigan Street, and two at each pier otherwise. Ports in the top of the actuating rod at each single-acting jacking cylinder allow the hydraulic power unit to be located on one side of the channel on a stationary part of the structure. Ball valve connections allow thermal adjustment and slight movement without use of hoses at jacking cylinders.

- Up-start and leveling features similar to an elevator were used to soft-start and soft-stop the span. Fixed displacement pumps have traditionally been selected for quiet operation. Pumps are turned off when span is lowered, since span lowers by gravity. Cylinders are single-acting.
- Spring set, hydraulically released caliper brakes. The brake calipers engage with vertical plate brake rails mounted on the lifting legs, one set at each corner. The brakes are used for holding the span in place whenever the hydraulic system is not operating. The brakes also automatically engage should a power failure occur, and can be activated if the need arises for an emergency stop.

- Compact piers. The lifting legs, counterweights, sheaves, and counterweight ropes, together with all machinery and jacking cylinders, are all located below the roadway deck, within the confines of the piers. The piers require compact construction so the flow of the narrow river is not impeded.
- Automatic, counterbalanced and gravity operated roadway barriers that rise into position immediately as the lift span rises.
- Low temperature hydraulic fluid, so there is no need for heat tracing of hydraulic lines.

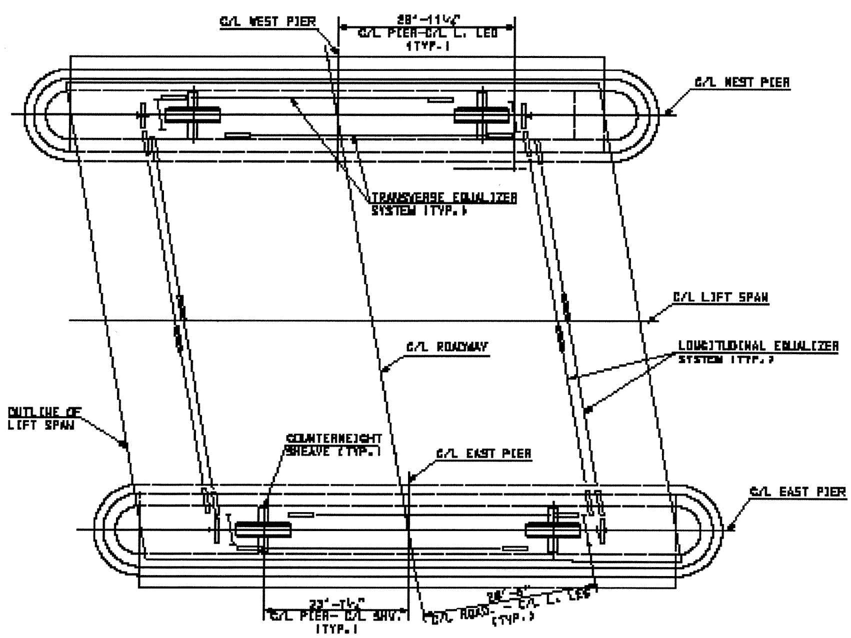


- Simple joystick-operated electrical directional and speed control. The electrical system was required to remain as simple as possible, and to essentially retain the sequence and "feel" of previous systems. The hydraulic and electrical systems could perform the same internal functions in a different manner than had been done in the past, but the operator should not know the difference in the way the bridge was to be controlled from the console. Also, the City was against both the use of variable displacement pumps and of electronic ramping for proportional valves.

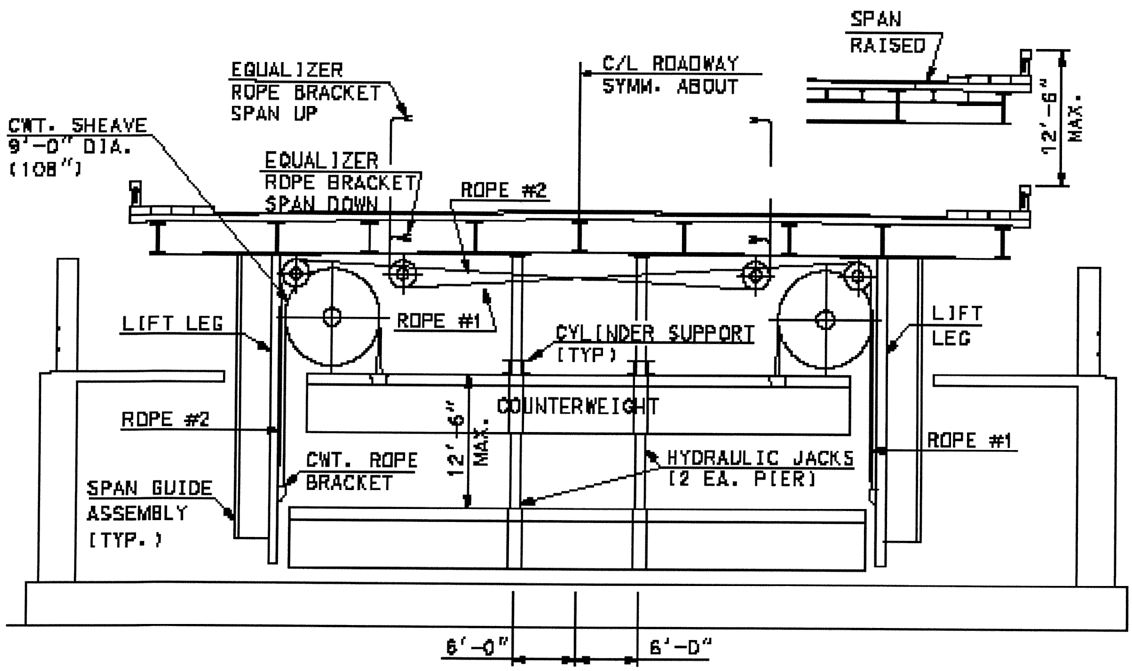
Special Requirements for Knapp Street.

During preliminary design it became evident that the larger size of the new bridge and its skew with the river would lead to several changes from that of previous designs.

- The skew of the channel required that the piers and ends of the lift span also be skewed. This would complicate the framing of the structure, and would



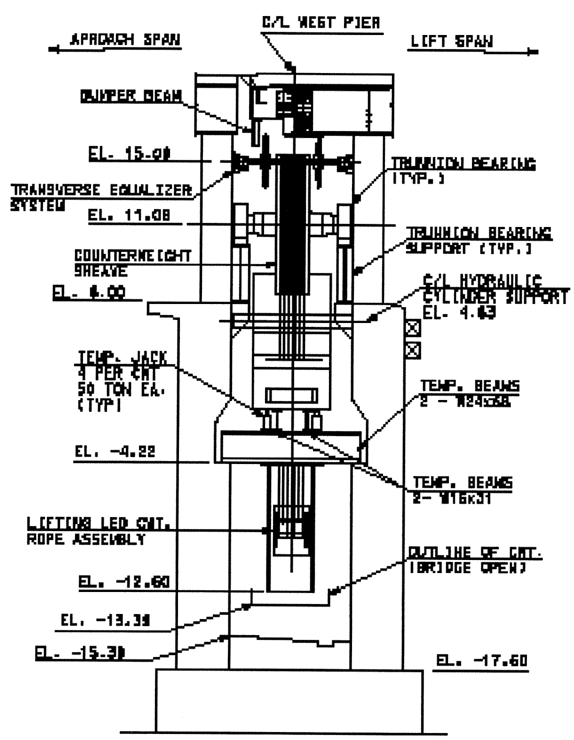
LIFT SPAN GENERAL PLAN
EQUALIZER AND COUNTERWEIGHT SYSTEM



SCHEMATIC SECTION AT WEST PIER
LOOKING EAST
N.T.S.

make the machinery area within the piers more compact than usual. The required skew of the steel framing for the structure would be especially tricky at the corners where the lifting legs were located. Since the lifting legs tie in to so many features, and there is vertical movement occurring, the location and configuration of all features would have to be laid out carefully to avoid any interference.

- The width and associated weight of the span (89 feet, 350 tons) would require higher capacity cylinders than at Michigan Street. A pair of cylinders would be used at each pier (total of four for the lift span) to minimize the size of the cylinders. The distance between the jacking cylinders would be large enough within the pier to provide optimum stability.
- The existence of a 96" sewer line beneath channel near the centerline of roadway would limit the depth of the piers. This would, in turn, limit the height of the counterweight. The pier footing would require special treatment to ensure its stability without interfering with the sewer. The remainder of the pier would be constructed conventionally.
- Design includes accommodation of the lifting legs and machinery, including the counterweight. Temporary counterweight supports will be provided during construction. These will be dismantled and remain on the floor of the pier at completion.



SECTION AT WEST PIER
LOOKING NORTH
N.T.S.

Code Upgrades Required. The following features were also found to require upgrades from existing bridges to meet present-day codes:

- AASHTO Standard Specifications would require 1.50 inch diameter ropes to be supported by a 108 inch diameter (min.) counterweight sheave. This is the largest counterweight sheave size used to-date by the City, and makes the arrangement of machinery within the piers even more compact.
- The AASHTO Standard Specifications now require that the hydraulic system include diagnostic features not present at existing bridges.
- OSHA standards now require larger radii and larger step surfaces to be used if the City's preference for spiral staircases was to be satisfied.
- The requirements of the Americans with Disabilities Act (ADA) would now have to be taken into account in the operator house.
- The Wisconsin energy code now limits the amount of power consumption used for heating and cooling based on square foot area of occupied space.

Remote Control Requirements. The scope of work also required the design of a remote control system to operate the lift span from a neighboring double leaf bascule bridge. Relay logic was desired for operation of the new lift span control system. To efficiently incorporate the remote control features, a PLC-based operating system was interfaced with the relay system, and fiber optic cables were utilized as a communication link between the local and remote sites. Remote control will be available from 2 blocks away at the existing Juneau Street lift bridge. To supplement the operator's visibility, 4 video cameras were included for mounting at the new bridge to be connected to monitor displays on split screens at the remote location. Fiber optics will also be utilized for pan and tilt camera control. This is the second remote control system used at the City's bridges. A previous system was installed at the Clybourn Street Lift Bridge to control the Wisconsin Avenue Bridge.

Requirements for Operational Improvement. In addition to the changes above, existing Milwaukee bridges were not perfect and operational improvements were desired. One irritation to City of Milwaukee personnel at existing bridges is the problem of oscillation during operation. While it is not unsafe, the tendency for bridges to oscillate slightly, or "walk" as they open and close, sometimes results in uneven seating. This requires the operator to raise the span slightly and lower again for better seating, prior to opening the roadway to traffic.

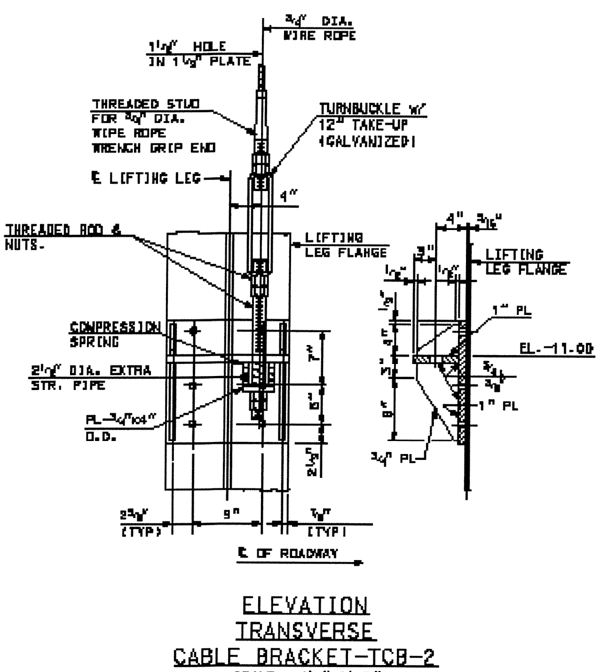
A study of this problem by HNTB revealed that there were two probable sources of the oscillation. These were surging in the hydraulic system and slackness in the equalizer systems. The following were seen as being part of this problem:

- The hydraulic systems on existing bridges are mounted in the pier supported operators house, but are used to power jacking cylinders on both sides of the channel. This is made possible by the following means. Jacking cylinders on the near-side pier are each fed with the full flow from the hydraulic power unit through a port on the bottom of each cylinder. While half of the flow is used to extend these near-side jacking cylinders, the remainder of this fluid is allowed to pass through a bore in the actuating rod and through piping across the lift span to power the cylinders on the opposite pier. The far side jacking cylinders are powered through the same type port at the top of their actuating rods, and an identical bore through the rod. There is, therefore, no need for long runs of hose or other type of flexible hydraulic conduit between the piers and the lift span, and only a need for very limited adjustment for movement near the cylinder ports. However, this unconventional arrangement was seen as one probable cause of surging.

- Another feature of existing hydraulic systems is two-stage, solenoid operated "up-start", "up-stop", and "leveling" valves. These valves are the same as those used in hydraulic elevators for buildings, now used to accelerate, decelerate, and seat the span in a two-stage manner. However, controlled acceleration and deceleration is not available by this means, so hydraulic shock is introduced.
- Slack was observed in equalizer ropes where oscillation was most evident. Compression springs at the ends of these ropes are used for adjustment to ensure tension in the ropes. Over time, rope stretch needs to be removed by readjusting the ropes.
- Only one limit switch was used to detect the fully closed condition of the lift span at existing bridges. While the operator would receive indication that the span was seated, the actual condition at one or more corners might be different.

In order to improve smoothness of operation, HNTB proposed to improve hydraulic equalization between the jacking cylinders and to provide a smoother means of acceleration and deceleration. Slackness in the ropes would also need to be addressed. Providing better indication of actual seating of the span was also seen as a desired improvement.

Due to problems experienced in previous projects, variable displacement pumps and proportional valves with amplifier cards for ramping were not desired, so a different means of smooth acceleration and deceleration had to be used.



ELEVATION
TRANSVERSE
CABLE BRACKET-TCB-2
SCALE: 1½"=1'-0"

To minimize bridge oscillation HNTB proposed to equalize pressure and flow to all cylinders by using tee connections between the two piers. This required a flexible fluid conduit, added between the lift span and the near side pier. A second feature proposed was the use of cam operated throttle valves to provide controlled span acceleration and deceleration. The use of wedge shaped actuators on the ends of small hydraulic cylinders at the hydraulic power unit will enable this be accomplished without ramping through amplifier cards.

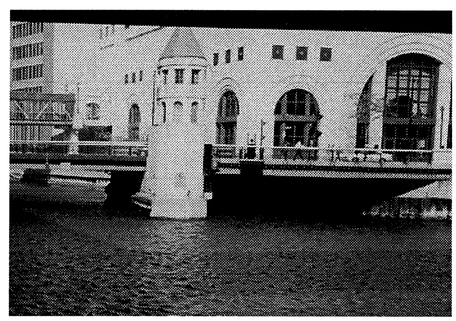
A recommendation to monitor the tension in the equalizer ropes as they stretched over long periods of use was also made. Since it would be desirable to verify that both ends of the lift span were fully seated, thereby ensuring the roadway and sidewalk joints are flush with each other, a fully closed switch was proposed at each pier. Previous bridges have had only one fully closed switch.

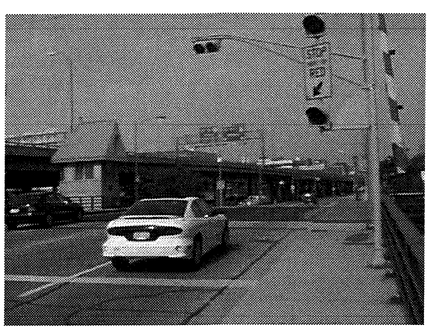
Requirements for Additional Safety. Another need was for additional safety when the span was in the raised position, to prevent any bleeding off of the hydraulic fluid that would allow the jacking cylinders to retract. A previous incident involved the jacking cylinders retracting prior to the release of the brakes. This resulted in one of the lift spans falling approximately 4 feet. A feature added to existing bridges, now including Knapp Street, is a clamp connection between the top of the jacking cylinder cap and the lifting girder. The jacking cylinders can retract no more than one-half inch when this clamping feature is present. However, a new safety feature was also added by HNTB – a piston-type accumulator. The accumulator allows an interlock to be placed in the hydraulic system, requiring it to be fully pressurized prior to operation or release of the brakes. The accumulator also absorbs pressure spikes.

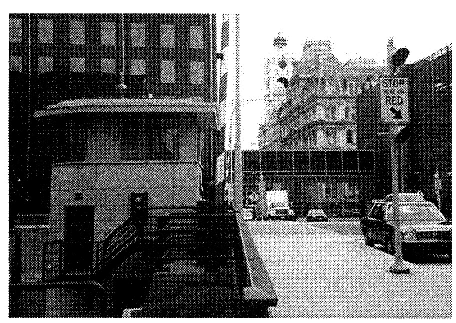
Hydraulic system diagnostic features were added to the AASHTO Standard Specifications in 1988, after the most recent vertical lift bridge was designed. Features now included are high and low pressure switches, high and low fluid level switches, and high and low temperature protection features. Interlock features are preceded by warnings at less critical levels in each case.

In addition to the above, the use of higher hydraulic pressures was implemented, as allowed by AASHTO standards. All hydraulic equipment is now rated at 3000 psi working pressure. Previously, hydraulic pressures were limited to approximately 500 psi, utilizing larger jacking cylinders of less pressure rating. Pressures will be limited to between 1300 and 1500 psi, under AASHTO specified loads, however. Design against buckling of the jacking cylinder limits the minimum bore diameter, so no higher pressures are required. However, the 100 hp main motor allows operation against somewhat higher snow loads by increasing the pressure settings.

Architectural Design



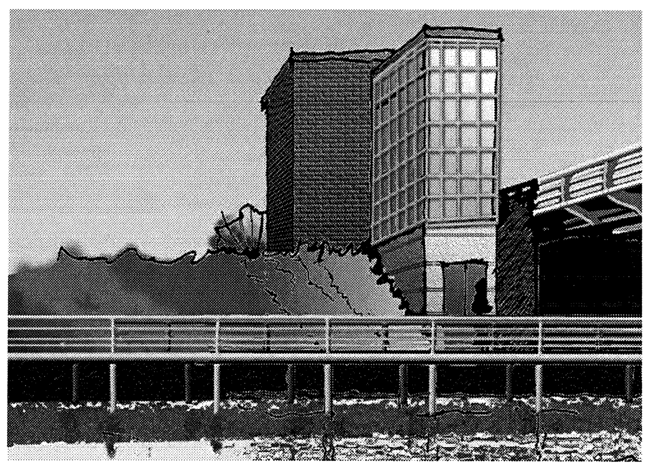




Milwaukee's existing bridges exhibit a variety of operator house styles, while maintaining very similar functional features. An attempt has obviously been made in some cases to blend into the old-world architecture of the neighboring area, while more modern motifs have been used at other houses.

For the new Knapp Street Bridge, the original plan included mounting between one and four houses on the piers supporting the lift span. One house would be functional for operation, while any others would be merely decorative, for symmetry, and would include only storage areas and possibly restroom facilities. While these options were considered, various motifs were discussed to reflect other features in the area. These ranged from the traditional and old-world historical, to the motorcycle theme to be presented by the new Harley Davidson Museum, to the scaling down of the theme presented at the recently completed Milwaukee Art Museum on the lakeshore. The City Planning Department worked closely with HNTB to reach an acceptable design. Another option then came to the fore: The bend in the river allowed consideration for placing the operator house on the west bank rather than on one of the lift span piers. This would be in a location along the river walk that was to be extended as part of the project. Visibility was found to be acceptable for the roadway and sidewalks, as well as the river. It would also not be necessary to provide multiple houses to maintain the symmetry under this plan.

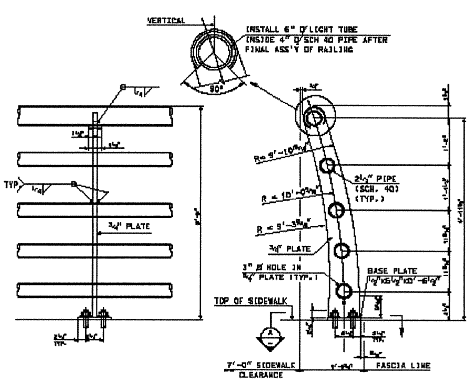
Further joint development by the City planner and HNTB led to the selection of an L-shaped glass and brick structure. This was successfully proposed to the City's art commission, gaining their approval quickly through the experience of the City planner. The Norman brick selected is gray with a tinge of blue, and is reminiscent of that found in other buildings in the area. The large amount of glass, meanwhile, appropriately reflects other nearby modern buildings, while allowing the best visibility from various parts of the house. The emphasis placed on aesthetics is unusual in projects of this type, and the outstanding cooperation of City personnel smoothed the process to obtain an excellent result.



The new operator house is designed to provide space for the electrical and hydraulic drives, in addition to control equipment and facilities for the operator. Two lower floors provide the necessary space for the hydraulic power unit, the electrical power and control apparatus, the HVAC equipment, and restroom facilities. The third floor provides space for the operator.

OSHA and ADA requirements have taken effect since the most recent vertical lift bridge was built in the mid-'80s. One of the preferences and trademarks of City of Milwaukee bridges is the use of spiral staircases. Because of the new regulations, however, the radii of these stairways had to be increased, along with the amount of space required. Since the operator and other personnel are required to be able bodied for their work, a waiver was obtained regarding some of the ADA requirements for the bridge and operator house.

Another architectural feature, again the result of exceptional cooperation and coordination of interests, was the incorporation of lighted handrail on the lift span. A light tube system will be installed in the top rail of the approach and lift span pedestrian railings. A ceramic window in the rail allows the light to be transmitted downward. A reflector assembly reflects light from a 150W metal halide lamp. The lamp assembly is easily accessed for maintenance through the ceramic window, but is also vandal-resistant. The handrail light will appear decorative when observed from river and shore.



PEDESTRIAN RAIL POST
TYPE A
1 1/2" = 1'-0"

Acknowledgement

The Park East Freeway has now been demolished and the Knapp Street Bridge is under construction. HNTB thanks the City of Milwaukee's George Roemer and other personnel under his direction for their great assistance and cooperation during the design of this project. The City of Milwaukee's Department of Public Works is also to be commended for their work in the development of this bridge type during past projects.