Herrington Lake Bridge – Lowering of a 200-ft Caisson

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ABSTRACT: Construction of an 830-ft, three-span bridge over Herrington Lake in central Kentucky presented a unique set of engineering and construction challenges. One challenge was the selection of means and methods for erection of 350-ft plate girder spans without falsework in the 700-ft wide lake. The second challenge was developing a method of construction of the center pier, located in the deepest part of the popular recreational lake where depths exceed 200 feet.

INTRODUCTION

Construction of the new Herrington Lake Bridge, carrying Route KY 152 traffic over the 830-ft crossing of Herrington Lake, came with a unique set of challenges. The most notable challenge, and the focus of this paper, being the center pier construction, which is located in the deepest part of the popular recreational lake where depths exceed 200-ft.

Photo 1 – Existing Truss Structure

The existing deck span structures (See Photo 1 and Photo 2) were considered beyond repair by the Kentucky Transportation Cabinet Department of Highways (KYTC), and a new structure was determined necessary. The new structure is to be located just off alignment of the existing bridge and will be built while the existing structure remains in service.

Photo 2 – Existing Truss in Poor Condition

Various design alternatives were considered for this design-build project, including Conventional Trusses, Precast & CIP Segmental, Cable Stayed, Suspension, and Arches. In the end, a conventional deep steel plate girder system was selected for the superstructure. The KYTC determined the more elaborate structures, which some would have eliminated the center pier in the deep lake, would require too much inspection.

The new superstructure is comprised of a conventional 2-span 350-ft continuous 10-ft deep steel plate girder unit and a 130-ft prestressed end span unit (See Photo 3).

The aforementioned center pier consists of 180-ft tall drilled shafts with 40-ft rock sockets (See Photo 3). Due to the extreme water depths (winter pools in excess of 200-ft), and lengths of the 8'-9" diameter steel casings, traditional barge anchoring and hoisting were not considered feasible. Not to mention, the deep center pier was designed to include 36-ft x 36-ft x 3'-4" concrete diaphragm braces at third points, where water depths could exceed 120-ft. A steel diaphragm brace was considered not acceptable due to required underwater inspection.

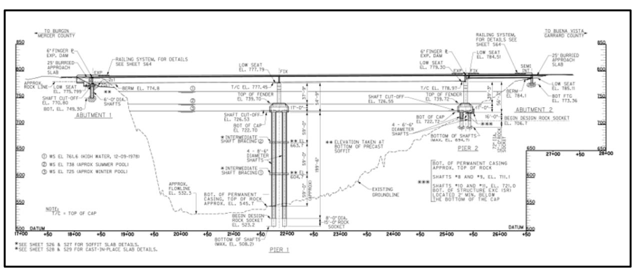

Photo 3 – Elevation View of Structure

Ultimately a construction method was selected to segmentally construct the casing and concrete braces on a barge platform and lower the system as a unit with strand jacks.

DEEP WATER PIER LOWERING SYSTEM DESIGN

A pre-bid concept design was developed by the Genesis and Walsh team to incrementally construct and lower the 200-ft casing system to the rock bed below.

Working from the bottom of the casing up, the lowest level of the permanent casing was modified to include high capacity support brackets. The support brackets would be designed to carry the full 1900-kip design load of the constructed foundation unit and rested on a sacrificial underwater lowering frame (See Photo 11). Note that this total design load included an incremental lowering study taking into account buoyant effects of the underwater portion of the casing.

The underwater lowering frame was comprised of heavy W36 and W40 framing. The lowering frame had two functions: 1) provide direct support of the bottom of the casing and 2) serve as the anchor point for the strand jacks. The (31) 0.6" dia. strands (for each strand jack) extended from the lowering frame up to a steel grillage system supported by the (2) 120-ft x50-ft barge platform (See Photo 4). Flexi-float barges were used because of limited space for barge launching near the bridge structure.

The strand jacks rested on a series of heavy W40 grillage beams which spanned between two sets of (2) 6-ft deep plate girders spanning between the barges. The plate girders were fabricated by the same supplier of the permanent bridge girders.

Photo 4 – Fully assembled barge lowering platform prior to strand jack installation

The (4) strand jacks used for lowering were equipped with compact stands to achieve a rated capacity of 392 tons per jack.

Analysis of the heavy lift steel framing system consisted of a series of simple span beams equipped with large bearing stiffeners to transfer immense local loads. Barge stability analysis was also simplified by centering the falsework support of the frames on the two barge centerlines. In addition, the falsework extended 11-ft above the deck level which kept the system center of gravity (CG) lower and well within the metacentric height.

The primary concern in the analysis of the lowering system was ensuring the stability of the casing system throughout the lowering process. The concern stemmed from the approach to pick a 1900-kip load below the system CG.

In the end, because of the immense dead load of the casing, the wide strand jacks spacing of a 40-ft x 40-ft to gain mechanical advantage and the ability to lower each of the strands symmetrically with tight tolerances, the lower system was a very stable bobber.

LOAD TRANSFER AND ALIGNMENT CONTROL

Final load transfer of the casing load between the strand jacks to the rock bed required an ability to maintain both horizontal and vertical alignment of the pier casings. Vertical load transfer from the strand jacks was achieved by pouring a 40-ft x 40-ft x 5-ft concrete tremie footing above the lake bed rock after the casing was lowered into its final position. The tremie footing was formed with a steel frame suspended from the underwater lowering frame. The tremie frame was equipped with a rubber seal along the bottom edge to prevent leaking of tremie concrete (See Photo 5). The permanent steel casings were again modified to include (2) levels of 4" radial "donut" bearing plates to transfer the load from the casing to the tremie concrete (See Photo 6)

Photo 5 – Steel frame used to form the tremie concrete above the bottom of the lake

Due to the natural contours of Herrington Lake, +/-700-ft width and +/-200-ft minimum depth with steep shoreline drop-offs, conventional barge spudding was not feasible to maintain horizontal alignment of the pier construction flotilla. The horizontal alignment of the flotilla was achieved using a series of +/-400-ft 1-1/4" Dia. cable braces extending from the barges to rock anchors drilled in at the shore line (See Photo 7).

Photo 6 - Radial Bearing PL Added to Permanent Casing for Shear Load Transfer to Tremie Concrete

Photo 7 - Rock anchor used for barge horizontal alignment

One challenge in securing the alignment cables to the barges was a requirement to maintain the cables +/-20-ft below the water level to minimize impact on local boat traffic. A 20-ft downrigger was conceived that attached at the barge deck level and guided the alignment cables through deck mounted winches down to a custom fairlead system (See Photo 8).

Photo 8 – 20-ft downrigger used to anchor the barge below water level to avoid boat traffic

PREPARING BOTTOM OF LAKE

The conventional method of twisting the casings into rock to achieve a hydraulic seal was not an option since the casings were locked together at the intermediate braces. Instead, a large tremie seal (described in detail in the previous section placed) at the casing/rock interface was selected as the most viable option to achieve an effective seal. Knowing this, the preparation of the lake bottom became extremely important.

The lake is approximately 200-ft deep at the center pier location, however, the actual depth of silty-clay overburden was less than 10-ft. The volume of material required to be removed to expose the rock bottom was approximately 1000cy. Although this is not an extraordinary volume, the fact that the water is 200-ft deep, a solution other than just traditional clam shelling was selected. Javaler Marine was contracted to relocate the overburden from the bottom of the lake using a Toyo pump and transport the material through a closed pipe system to another area adjacent to the proposed alignment. Once the overburden was removed with the Toyo pump, Walsh finished removal of the more cohesive and firm clay lining the lake bottom with a clam shell (See Photo 9). A final pass with the Toyo dredge pump was completed to ensure the rock bottom was fully exposed. This was then preliminarily verified using a weighted sounding tape.

Photo 9 – 2.5CY Clamshell Bucket

Overall grade of pad was roughly 6" out of level over approximately 40-ft. A quick pass with a Hain 25,000# drop chisel was made to ensure significant deviations in the rock were minimized.

Once the rock bottom was prepared, a 6-ft tall rock berm consisting of Aggregate No. 23 (2" minus) was installed around the perimeter of the footing to serve as "cheap insurance" as a secondary containment if the steel tremie frame leaked. A final 3D sonar scan was taken after the rock berm installation to verify the sounding tape measurements prior pouring the tremie seal (See Photo 10).

Throughout the tremie seal pour, no leakage was observed from steel tremie frame, but installing the rock berm was a very cheap insurance policy that would be employed again if this method is re-used.

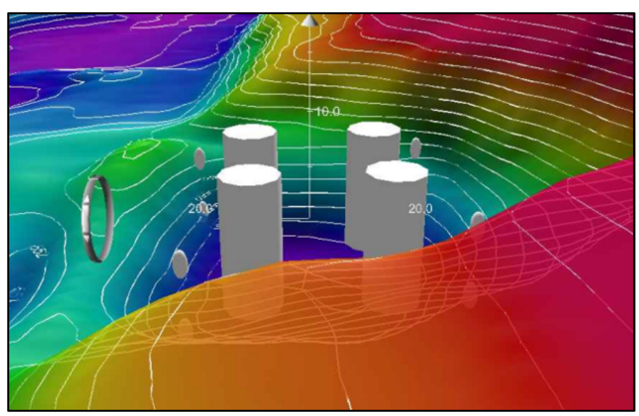

Photo 10 - Results of 3D Sonar Scan Showing Rock Berm at Left Edge of Screenshot

DEEP PIER LOWERING: PROCESS EXPLAINED

The lowering process can be summarized as a bottom up approach constructed from above the water and incrementally lowered after each stage was completed. There were several steps that will be described below:

1. Construct Lowering Platform
2. Install/Weld ~60-ft Casing Section
3. Form/Pour/Strip Intermediate Braces
4. Pour Tremie Seal/Lower Casings to Rock

1. CONSTRUCT LOWERING PLATFORM

The project critical path after mobilization followed the deep-water pier through completion of substructure. This presented a unique challenge in that substantial falsework was required to be installed very early on in the project. Continuous coordination between Genesis, VSL and Walsh allowed for prompt design/drawing development which led to an on-time delivery of main support members. Walsh's extensive equipment inventory allowed for an on-time mobilization of all cranes and Flexi-Float sectional barges required to support the lowering system frame as components were fabricated and delivered. VSL was also able to supply the strand jacking equipment and material to meet the project schedule.

2. INSTALL / WELD ~60-ft CASING SECTION

Once the lowering system was assembled, the first lift of 4ea 68-ft x 102" ID x 1.5" wall casing was installed in the lowering tray. The casings were supported by W40 beam sections (See Photo 11) welded 20-ft above the bottom of the casing and welded to the frame. The first lift of casings was then lowered approximately 40-ft to facilitate the construction of the first intermediate brace (See Photo 12).

Photo 11 - Lower Lift of Casing Connected to Lowering Tray

Photo 12 - First Lift of Casing Installed, Ready to Lower

3. FORM/POUR/STRIP INTERMEDIATE BRACE

Upon receipt of bid documents, one of the first questions asked by the team was "How in the heck do they think we're going to install a 3'-4" CIP brace 120-ft under water?". This ultimately led to the decision to develop a method to cast these braces above water and then lower. A soffit consisting of plywood and aluma beams was designed to be supported by W36's spanning across the main 6-ft plate girder support beams. Nelson studs were shot onto the casing, rebar and forms installed, concrete placed (See Photo 13), next lift of casing spliced, and finally the system raised approximately 6-ft to allow workers to strip the plywood/aluma beams from under the brace. The W36 support beams were then slid out utilizing Hillman rollers temporarily attached to the casings. The entire system was then lowered approximately 60-ft and this process was repeated for the remaining two braces.

Photo 13 - Intermediate Concrete Brace Pour

4. POUR TREMIE SEAL/LOWER CASINGS TO ROCK

+Due to the water depths and dangers and inefficiencies associated with sending divers to the bottom of the lake, the construction team decided to employ a tremie seal. To contain the concrete, a 36-ft x 36-ft x 5-ft box consisting of W30's stacked together (refer to Photo 5 above) was lowered with the casings and eventually came to rest on the bottom. During the pour, the casings were held approximately 4-ft above rock. The concrete was placed through one casing via tremie pipe and monitored through three other casings using sounding tapes. Once the concrete level was at least 5-ft above the rock, the system was lowered into the plastic concrete until one casing contacted the rock bottom. The system was then adjusted with the strand jacks to achieve the very stringent verticality tolerance of 0.5%. A minimum amount of load was transferred to the rock, and then the countdown began. A small crew camped out on the barges periodically surveyed the pier to ensure there was no movement throughout the night. Note that the water level was controlled with the dam operations during this critical phase of construction. The surveys were performed to check for movement of the radial bearing plates (refer to Photo 6 above) in the tremie concrete. Field cured cylinders were stored in a cure box equipped with a heater to mimic the actual temperature of the in-situ concrete at the bottom of the lake. Once the test cylinders broke above 1,000psi, the crew completed the lowering sequence and transferred load from the strand jacks to the tremie seal. The entire weight of the structure was now supported by the radial bearing plates and the seal concrete. Zero movement was observed during the load transfer process.

ROCK SOCKET & DRILLED SHAFT INSTALLATION

During the bid process, it was decided to employ a reverse circulation drill system. The size of the floating platform required to support a pile top rig with 220-ft of drill string would not be feasible. Early discussions with Roc Equipment led the team to select a Buma RCD R3030 to drill the 8-ft x 37.5-ft rock sockets required for this pier.

Fluctuating lake levels during drilling operations forced to team to extend the permanent casings by up to 50-ft to ensure the floating equipment below would not bind up on the drilling platform. When the first shaft was tipped out, the measurement from the drill platform to the tip was 274-ft, an incredible feat for all involved.

Photo 14 - Buma RCD Ready to Insert Drill String

Upon completion of drilling, sonar caliper inspection was performed to ensure verticality tolerances were met, and more importantly at this stage to confirm the presence of karst features in the rock. Bulges in the sockets extending radially up to 3-ft were observed at elevations coinciding with loss of water during the construction borings. To minimize risks associated with uncovering a larger void in this deep of a shaft, KYTC directed Walsh to remediate each of the four shafts. This was completed by filling in the socket with the same tremie concrete mix minus the hydration stabilizer, topping out at an elevation roughly 5-ft into the casing to ensure sufficient head pressure to push the fresh concrete well into the voids, and then re-drill to final tip elevation. A final Sonar Caliper inspection was then completed to ensure tolerances were met.

Photo 15 - 4100 Ringer Setting Rebar Cage

Rebar cages for these long shafts were initially planned to be tied horizontally in two pieces, tripped into vertical position using two cranes, then spliced over the hole. During work plan development meetings, Walsh's installer proposed tying the cages vertically and suspending from the barge until installation. The splice over the hole would still be necessary due to the length of the cages surpassing the available headroom of the crane. Having a body of water with depths approaching 200-ft facilitated this plan and allowed all temporary crush rings and a second support crane to be eliminated from the operation. Upon installation of the cage, concrete was placed via tremie pipe.

SUMMARY

This paper was written upon successful completion and acceptance of the four deep water shafts. In retrospect, this construction method resulted in the successful completion of a very challenging and risky operation. In the future, this method could be employed again but would only be recommended as a last resort.

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