PROJECT

The Falls Bridge: A Historic Location Reimagined

by Dr. Harold Walton, HNTB Corporation

Located in Blue Hill, Maine, the Falls Bridge (Maine Bridge #5038) spans a reversing waterfall at the narrows between Blue Hill Bay and Salt Pond. With typical tidal cycles exceeding 10 ft, the narrow 100-ft clear opening between bridge abutments and granite causeways restricts water flow, causing water velocities of up to 15 ft/sec coupled with standing waves that provide a visual spectacle as well as recreational opportunities for whitewater kayakers. The site also supports a diverse array of ocean wildlife and waterfowl.

When it was constructed in 1926, Falls Bridge was a testament to the engineering of its time. The single-span concrete tied-arch bridge was supported by cast-in-place gravity abutments with wet-laid granite masonry facing, while dry-laid granite gravity retaining walls supported the approaches. However, by the 2010s, the historic structure, which was eligible for listing in the National Register of Historic Places, showed signs of substantial deterioration, a consequence of its age and the harsh marine environment, and was in need of major repair.

The 20-ft curb-to-curb width of the superstructure was insufficient for current design criteria for two-way traffic. The narrowness of the bridge was exacerbated by poor roadway geometrics; built on a tangent at the bottom of two sag curves, each approach has grades greater than 11%, resulting in a 20-mph posted roadway speed. The recreational aspects of the area adjacent to the bridge drew crowds during summer months, and the roadway width, without shoulders, created unsafe conditions. More width was needed for pedestrian and motorist safety.

Rehabilitation was considered but was deemed impractical given the advanced deterioration of the structure. The existing superstructure width could not meet traffic and pedestrian demands, and the installation of adequate crash railings would further limit pedestrian access. The concrete hangers inhibited sight lines, obscuring the visibility of pedestrians from passing vehicles and resulting in general safety concerns. The bridge's tie girders lacked the capacity to support modern design loads, necessitating strengthening. The floor beams and deck—heavily spalled and with corroded reinforcing steel—

The new precast concrete superstructure and rehabilitated concrete abutments showcase a combination of historical preservation and architectural features that highlight the iconic beauty of the reversing falls and the site. Photo: Maine Department of Transportation.

profile

FALLS BRIDGE / BLUE HILL, MAINE

BRIDGE DESIGN ENGINEER: HNTB, South Portland, Maine

PRIME CONTRACTOR: Cianbro, Pittsfield, Maine

CONCRETE SUPPLIER: Owen J. Folsom Inc., Old Town, Maine

PRECASTER: J. P. Carrara & Sons Inc., Middlebury, Vt.—a PCI-certified producer

The aging concrete tied-arch superstructure before demolition. Note the visible spalls in the concrete tie girders and the concrete abutment cap. The contractor repointed mortar and installed waterproof caulking in the masonry joints of the original abutment before superstructure demolition to reduce the risk of damaging the stone facing of the abutments. Photo: Maine Department of Transportation.

required a complete replacement. Furthermore, the concrete abutment caps were severely cracked, and their repair would require temporary support for the 600-ton superstructure.

Full replacement options were evaluated but ultimately dismissed due to the site's historic significance and the local community's aspirations and expectations. The project involved a comprehensive public engagement process, which included a local bridge advisory committee of project neighbors, local officials, and other community members that convened more than 20 times. The committee played a crucial role in communicating the need for bridge replacement, soliciting public feedback, and understanding the community's priorities for a new bridge.

The existing bridge and its setting had traditionally been a source of community pride, and the community expressed a strong preference to preserve the structure's features, including the water flow through the current channel and the granite substructures. This community sentiment led to the selection of superstructure replacement as the preferred option. Superstructure replacement addressed the deficiencies with the superstructure and facilitated access for the repair of the granite-faced concrete abutments. The superstructure replacement preserved the historic stone-faced abutments and approach walls, maintained the hydraulic characteristics of the reversing falls, and minimized the amount of challenging in-water work. Aesthetic enhancements included a crash-compliant decorative steel railing with pickets, pedestrian-friendly stamped and colored pavement on the shoulders, and concrete fascia panels with a bottom radius and accompanying reveal. Inspired by the old bridge, the precast concrete fascia panels give the new superstructure an arched appearance, emulating structural support. Reinforcing bars embedded into the concrete fascia panel are cast into the concrete curb to provide a durable, concealed connection.

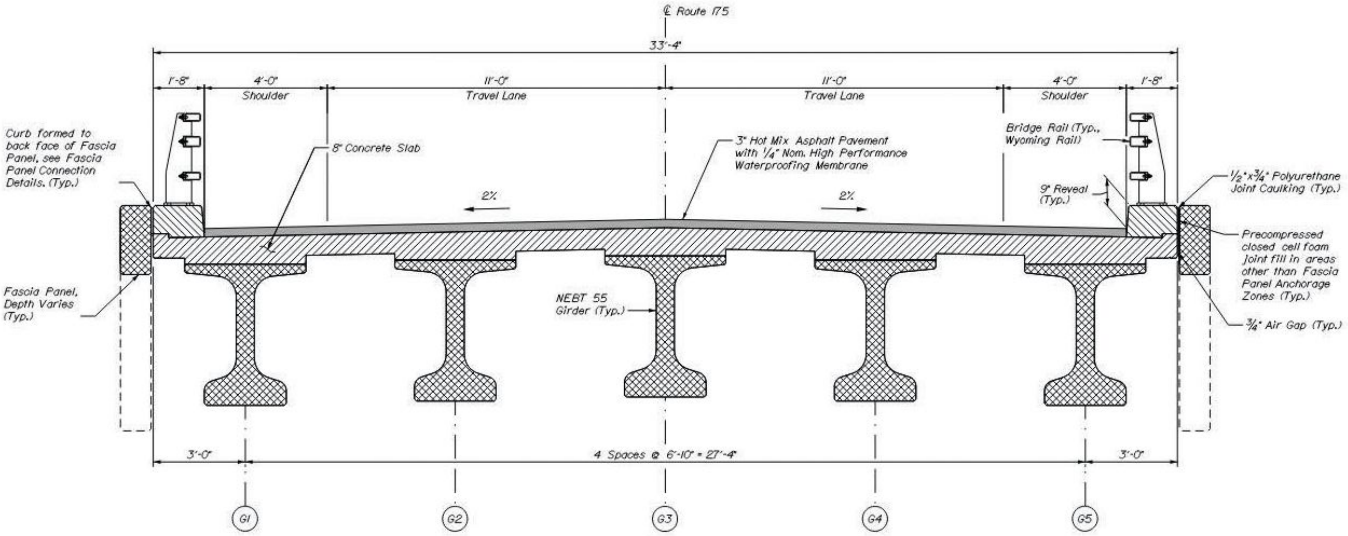
Aesthetic features such as a picketed crash barrier and radiused fascia panels with pencil-line insets create visual appeal for the new superstructure while also improving the safety of the roadway with unobstructed driving sight lines. Photo: Maine Department of Transportation.

MAINE DEPARTMENT OF TRANSPORTATION, OWNER

BRIDGE DESCRIPTION: 103-ft-long prestressed concrete Northeast bulb-tee (NEBT) girder bridge with cast-in-place concrete deck and precast concrete slab-beam approach spans

STRUCTURAL COMPONENTS: Five prestressed concrete NEBT-55 girders with stainless steel prestressing strand; sixteen 2-ft 7-in. × 4-ft 0-in. precast concrete slab beams; 8-in.-thick cast-in-place concrete deck; and cast-in-place concrete abutment caps and grade beams supported by micropiles. All superstructure nonprestressed reinforcement is Grade 100 high-chromium, low-carbon steel.

BRIDGE CONSTRUCTION COST: $9.5 million ($1420/ft^2)



Main span typical section. Figure: HNTB.

Superstructure

The 103-ft main span of the replacement superstructure has five 55-in.-deep prestressed concrete Northeast bulb-tee (NEBT) girders with an 8-in.-thick cast-in-place concrete deck. The girders used concrete with an 8-ksi design strength at transfer and 10-ksi ultimate design strength. With a clearance of 6 ft over the mean high water of Blue Hill Bay, the superstructure of the bridge is within the splash zone and contains corrosion-resistant reinforcement. All superstructure reinforcing bars, including stirrups and confinement reinforcement in the NEBTs, are Grade 100 high-chromium, low-carbon steel per ASTM A1035.[1] The prestressing strands in the NEBTs are Grade 240 duplex stainless steel per ASTM A1114.[2] Plastic spacers were installed between the strands and the stirrups to disrupt galvanic flow between the dissimilar metals. This was the first Maine Department of Transportation project to use stainless steel prestressing strands, and one of the first projects in the United Sates to use stainless steel prestressing strands as the primary superstructure reinforcement.

The American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*[3] does not provide guidance for designing prestressed concrete with stainless steel prestressing strands. The NEBTs were designed in accordance with guidance developed by the Florida Department of Transportation (FDOT) in its Structures Design Bulletin 21-02.[4] The minimum 1.4% strain at rupture of Grade 240 ASTM A1114 stainless steel strand is low compared with the minimum 3.5% strain at rupture of Grade 270 ASTM A416[5] carbon steel prestressing strand; therefore, strength design was performed using the strain-compatibility method with nonlinear stress-strain behavior of the strand and concrete strength modifications to the Whitney stress block. Based on the FDOT design bulletin, the flexural resistance factor to be used for a tension-controlled stainless steel prestressing strand girder is 0.75, rather than the 1.0 flexural resistance factor for a typical tension-controlled carbon steel strand reinforced prestressed concrete girder. Typically, carbon steel prestressing strands are pretensioned up to 75% of f_{pu} (specified tensile strength) during fabrication; for this project, pretension of the stainless steel strands was limited to 65% of f_{pu} as based on the FDOT bulletin. The beams were fabricated with fifty 0.62-in.-diameter strands in the bottom of the beam and four strands in the top of the beam. All strands are straight, and no strands are debonded.

Given the reduced ductility of the stainless steel prestressing strand,

A prestressed concrete Northeast bulb-tee exterior girder is erected for the main span. The girders were treated with a pigmented protective coating to create a visual contrast with the uncolored concrete fascia panels. Photo: Maine Department of Transportation.

Precast concrete beams for the south approach span are installed over a concrete slab and concrete extension walls that cap the dry-laid granite retaining walls. The prestressed concrete bulb-tee girders of the main span are visible in the background. Photo: Maine Department of Transportation.

procedural adjustments were required during fabrication. During detensioning of the first pair of girders, three strands prematurely ruptured. It is thought that elastic shortening of the concrete girder as the strands were detensioned caused increased tension, calculated to be 80% of the tensile strength and 57% of the minimum specified rupture strain of stainless steel strand. It is possible that the beam formwork or the pretensioning bulkheads may have caused local stress concentrations in the strand, leading to brittle failure. To rectify the safety and girder durability issues, the second set of beams were redesigned. In these beams, the middle 16 of 54 total strands (the last strands detensioned) were only pretensioned to 58% of f_{pu}. There was sufficient leeway in the design to keep the same number of strands—the beams were initially designed for zero tension under service loads and then revised to limit the service tension in the concrete to 0.3 ksi per AASHTO LRFD specifications Table 5.9.2.3.2b-1 for components with bonded tendons subjected to severe corrosive conditions. The second set of beams was detensioned without issue.

The existing dry-laid granite causeways of the 1926 bridge were constructed for a 20-ft roadway and were too narrow to support the 30-ft roadway leading up to the new superstructure. The new roadway is carried by approach spans that span the causeways with center-to-center bearing span lengths of 53 ft 9 in. (north approach) and 30 ft 3 in. (south approach). Supported by the existing abutments and by new concrete grade beams, the approach spans each consist of eight butted 2-ft 7-in.-deep by 4-ft 0-in.-wide reinforced precast concrete beams with 5-ksi concrete design strength supporting an 8-in.-thick cast-in-place concrete topping slab. The approach beams are conventionally reinforced with Grade 100 high-chromium, low-carbon steel meeting the requirements of ASTM A1035. No prestressing was used in the components of the approach spans. The contract gave the contractor the option of fabricating the nonprestressed concrete components.

Substructure

The gravity abutments from the 1926 bridge were rehabilitated to support the proposed superstructure. Bedrock is shallow at the site, and exposed bedrock outcrops are prevalent adjacent to the north approach causeway and in the channel. Borings taken through the abutments indicated that the north abutment had been founded on cleaned bedrock while portions of the south abutment had been founded on native till soils. To mitigate future settlement and undermining, the south abutment was underpinned with micropiles. Eight micropiles, each with an 11.875-in.-diameter casing and a no. 18 central reinforcing bar, were installed in 14-in.-diameter cored holes in the south abutment. The annulus around the micropile casing was tremie-grouted with a permeating grout. The grouting process also served to permeate and fill nearby holes, voids, and wide cracks within the existing abutments.

For both abutments, the loose bedding mortar between courses of stones was removed and replaced with cementitious mortar. Mortar joints in the tidal zone were sealed with epoxy caulking rated for saltwater inundation. Where possible, this work was done in the dry by working around the tidal elevations, and underwater work was completed with dive crews at slack tide. The concrete abutment caps were demolished and replaced with hammerhead cast-in-place concrete abutment caps to accommodate the wider roadway width of the proposed superstructure. The roadway profile was also raised to accommodate sea-level rise and to improve the vertical geometry of the bridge and roadway.

The approach spans are supported on one end by the rehabilitated abutments and on the other end by micropile-supported, cast-in-place concrete grade beams installed beyond the limits of the existing stone retaining walls.

Conclusion

In November 2023, a significant milestone was reached: the new superstructure was opened to the traveling public, and in June 2024, the project reached completion. The use of durable precast concrete with corrosion-resistant reinforcement will provide a low-maintenance facility in this challenging location. The completed project provides sufficient roadway width to safely accommodate pedestrian and vehicular traffic while maintaining the historic abutments and approach

AESTHETICS **COMMENTARY**

by Frederick Gottemoeller

Small bridges deserve thoughtful design, too. This is especially true if they overlook visual spectacles, such as a reversing waterfall that draws white-water kayakers and crowds of spectators during the summer months, or if they include historic, memorable, and still-capable structural features, such as granite-faced gravity abutments.

Thoughtful design requires consulting project stakeholders, including members of the community that surrounds the project, uses it every day, and takes pride in its appearance and setting. Doing so pays direct benefits. For one thing, it creates community understanding of the structural imperatives driving the need to replace or repair the structure. For another, it uncovers seemingly inconsequential enhancements that mean so much to a community and will determine the acceptance of the structure by future generations. At the Falls Bridge in Blue Hill, Maine, these enhancements included the decorative steel railing, stamped and colored shoulder pavement, and color coating of the precast concrete beams so that the arched concrete fascia panels stand out.

The decision to preserve and reuse the granite abutment walls was especially inspired. While observing the daily tidal cycle, spectators' attention is drawn to the supports of the bridge. Over the walls' almost 100-year life, the stone has stood up to the daily stress of nature. This is a testament to the stone's authenticity, durability, and obvious strength. The granite impresses in a way that no formliner-created "stone" can. It also extends the memory of the original bridge into the future. Blue Hill's Falls Bridge will continue to be a source of community pride for another 100 years.

Crews cored 14-in.-diameter holes in the south abutment before installing micropiles. Coring through the stone and concrete abutment was specified as a nonpercussive, low-energy method of creating holes with a low risk of damaging the facing stones at the abutment. Micropiles were installed through the precored holes, and this underpinning provides an alternative load path if the soil-supported abutment is undermined. Photo: HNTB.

walls to preserve the location's unique hydraulic features. New aesthetic enhancements, such as decorative railings and curved fascia panels, serve to amplify the natural beauty of the location while echoing the memorable sweeping lines of the original concrete arch bridge.

References

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2. ASTM International. 2020. *Standard Specification for Low-Relaxation, Seven-Wire, Grade 240 [1655], Stainless Steel Strand for Prestressed Concrete*. ASTM A1114/A1114M-20. West Conshohocken, PA: ASTM International.
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5. ASTM International. 2024. *Standard Specification for Low-Relaxation, Seven-Wire Steel Strand for Prestressed Concrete*. ASTM A416/A416M-24. West Conshohocken, PA: ASTM International.

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