THE CROSS STREET BRIDGE – A NEW FRONTIER FOR PRECAST CONCRETE

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ABSTRACT

From funding to design and construction, the Cross Street Bridge in Middlebury, Vermont is an infrastructure accomplishment that can serve as both inspiration and a blueprint for others desiring to integrate infrastructure improvements into the fabric of the community. This paper discusses the development of the bridge —the longest simple span, precast, post-tensioned, spliced girder known in the US—from conceptual design through final design and construction, providing detail on the team's design-build approach and the challenges faced and overcome.

Keywords: Creative/Innovative Solutions and Structures, Design-Build, Post-Tensioning

A SMALL NEW ENGLAND TOWN (PROJECT INTRODUCTION)

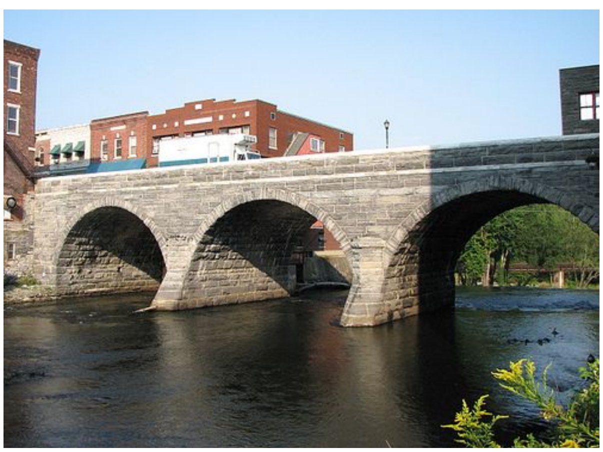
The project setting is Middlebury, the shire town of Addison County, Vermont, which was chartered in 1761. This picturesque New England town, surrounded by rolling farmland is listed on the National Register of Historic Places and is home to many downtown shops and restaurants, as well as the library, architecturally distinguished churches, and public buildings. Otter Creek, the state's longest river passes through the heart of the Town creating a division, but also pulling the Town closer together as a focal point. On one side of the Creek are the Town's rescue services, as well as the primary transportation corridor on the western half of the state, US Route 7; on the other side is the Town's hospital, the bustling downtown block, and the prestigious Middlebury College.

THE COLLEGE

Named after the Town, Middlebury College defines the Town as much as the Town defines the College. It is a relationship that spans more than two centuries, commencing with the College's foundation in 1800 when a few men of the Town took it upon themselves to build the college in a small Town, on what was then the American frontier.

As one of the top liberal arts schools in the nation, Middlebury College has a reputation for excellence beyond compare; and the commitment of the college to its hometown is unparalleled.

THE BATTELL BRIDGE



The Battell Bridge

The last time a bridge was constructed in downtown Middlebury, Benjamin Harrison was President and Thomas Edison was taking out a patent on something called a motion picture camera. Throughout history, the Town and college have relied on the Battell Bridge; a narrow stone arch bridge crossing. 119 years after construction, downtown Middlebury's lone bridge is showing signs of deterioration, and there is a real possibility that major rehabilitation work will be needed in the near future. In the event of a bridge closure, the shortest detour is some 20 miles around.

A BRIDGE IN THE MAKING (HISTORY OF THE PROJECT)

The origins of the Cross Street Bridge Project date back more than fifty years. It has been a hot topic at numerous Town Meetings through the years and has been on the Selectboard agenda countless times. While the community has always agreed that a second bridge was a necessity, it had not been easy to reach a consensus on location or project funding.

THREE MILE BRIDGE

Located south of Middlebury, Three Mile Bridge was the only other crossing of Otter Creek in the remote vicinity of downtown. The bridge was destroyed by fire in 1952 and had left downtown Middlebury with the single crossing. Since the demise of Three Mile Bridge, the Town had been pursuing alternatives to rebuild a second crossing. Year after year the discussion continued: Where should a second crossing be constructed? How will the design and construction be funded?

PROJECT CONCEPTION

In recent years the discussion regarding a second crossing had taken on a new tone. The level of energy throughout Town was growing and residents were vocal at public meetings coming forward with their own ideas for a second bridge crossing. The residents pleaded with the state and town officials to take action. The increasing traffic congestion throughout Town, the ongoing public safety concerns over a single crossing, and the aging Battell Bridge all culminated in the spring of 2007 when a few members of the community formed a Bridge Committee to oversee the funding, design, and construction of a second bridge crossing in downtown Middlebury. As luck would have it, this group of Middlebury residents faced a frontier all their own.

PROJECT FUNDING

The first challenge of the bridge committee was to secure project funding. While a project of this need and of this size would ordinarily be funded through the Vermont Agency of Transportation (VTrans), after years of exhausting all avenues of funding with state government, including heavy legislative pressure, it was clear that VTrans would not be able to commit to this project for decades to come, if at all. Undeterred, the Bridge Committee began searching for alternative and innovative funding.

Through a preliminary bridge scoping report, the Town had determined a budget of $16 million was an appropriate number to complete all project goals. So after years of frustration and numerous dead ends a likely project proponent come forward with a pledge. In a fashion that is true to their commitment to the Town, in fall of 2007 Middlebury College made a pledge of $9 million to partially fund the project, with a strict condition that the bridge be open to traffic prior to November 2010. With the challenge of quickly funding the other $7 million for the project, the Town went to work compiling an innovative plan to provide the additional funding with a 1% local option sales tax with no impact to the Town's property taxes.

A PROJECT PLAN

Funding was now secured and the clock was ticking as the Bridge Committee moved toward defining a plan to make the project a reality. In the beginning the bridge committee was certain of two things: they wanted to build a bridge to extend the existing Cross Street over Otter Creek and into downtown, and they wanted the locally funded project to spend its dollars with local companies. J.P Carrara & Sons, a regional precast concrete supplier based in Middlebury specializing in precast/prestressed concrete bridge elements, and one of the Town's largest employers, was immediately brought to the table to assist the bridge committee define an approach for the project. It was clear from the beginning that this would be a precast concrete bridge.

DESIGN-BUILD APPROACH

With an innovative funding plan in place, the bridge committee set out with an innovative design-build project delivery plan as well. As first major transportation design-build project in Vermont, the approach allowed the project to go from conception to completion in under three years.

The design-build team was comprised of a lead contractor, Kubricky Construction; a lead engineering firm, Vannasse Hangen Brustlin (VHB); and a local precast concrete fabricator, J.P. Carrara & Sons. The team members had successfully worked together before and fell right into the groove of a cohesive working team. The early stages of the project were filled with planning meetings between the design-build team and the Bridge Committee for the purpose of capturing the vision of constructing an aesthetically significance structure that would integrate seamlessly into the landscape of this beautiful and historic New England community, while also staying within the $16 million project budget. Having the precast fabricator on board from the beginning of design proved to be invaluable to quickly narrow the range of options that would fit within the project budget.

PROJECT CONCEPTS

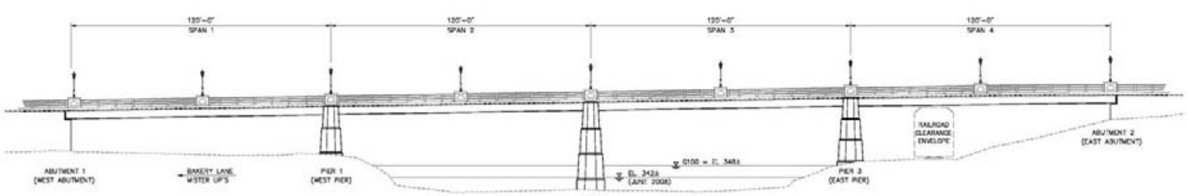
The bridge crossing spans three key features: a town highway, Bakery Lane, on the west approach; the Otter Creek, and an active Vermont Railway track on the east approach. These features limited the placement of the substructure components. The primary challenge in determining a span configuration was crossing the Otter Creek at approximately 160-feet between the toes of each river bank slope. The western approach over Bakery Lane was approximately 160-ft from the downtown area to the toe of the Otter Creek River Bank, and the eastern approach over the railroad was approximately 160-ft from the toe of the Otter Creek River Bank to the existing Cross Street, for a total required superstructure length of 480-feet.

BRIDGE CONFIGURATION CONCEPT 1

The first bridge layout proposed two piers placed at the edges of the Otter Creek Channel approximately at the toe of each river bank, requiring three span lengths of 160-feet each. This concept utilized 2000 mm tall (6’-6”) 160-foot long precast prestressed New England Bulb Tee (NEBT) girders. At 160-feet long, the NEBT 2000 shape would have been at the maximum for J.P. Carrara’s crane picking weight at the plant as well as at the maximum length for transporting capability. Another hurdle with this concept was the hydraulics of Otter Creek. The location of the new crossing is at a bend in the Creek. Geometrically aligning each pier with it respective river bank proved to be economically impractical. This substructure layout also proved to be less than ideal from a hydraulic standpoint, and upon discussion with State regulators it was expected that the Vermont Agency of Natural Resources (ANR) would not likely approve of the channel impacts that would be created by the substructures placed at the toe of each river bank in such a configuration.

BRIDGE CONFIGURATION CONCEPT 2

The second configuration placed piers at the top of each river bank as well as one pier directly in the middle of the channel, creating a bridge configuration with four equal spans of 120-feet in length. This configuration incorporated an additional pier and reduced the impact to the creek channel with only one in-water substructures. This four span configuration resulted in fewer cofferdams and reduced the individual precast span lengths from 160-feet to a more reasonable 120-feet, which made the use of 42” deep box beams a practical alternative to NEBT. The design-build team considered this alternative to be more attractive to state regulators for environmental permitting due to the reduction in channel impacts. However, upon consultation with Vermont ANR it became clear that permitting a pier in the center of Otter Creek would be an uphill battle and would cost precious time that this project could not afford. With limited options remaining, the Bridge Committee challenged the design-build team to completely span the Otter Creek and eliminate permanent channel impacts. From this request, the final bridge configuration was born.

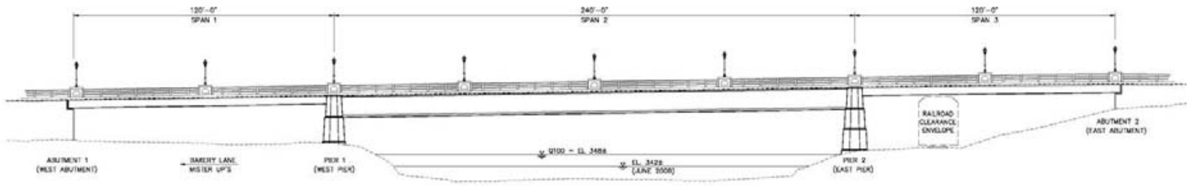


Bridge Configuration Concept 2

FINAL BRIDGE CONFIGURATION CONCEPT:
PRELIMINARY SUPERSTRUCTURE DESIGN

The third and final bridge configuration presented significant engineering hurdles. The challenge: span the Otter Creek without permanent channel impacts. The solution: remove the middle support and create a record breaking, 240-foot simply supported center span using precast concrete.

The revised 3-span structure of 120-foot approach spans and a 240-ft center span ultimately proved acceptable to Vermont ANR. All impacts to the channel would now be strictly temporary to facilitate the erection of the center span and ANR could define acceptable times of year for the impacts to take place.



Final Bridge Configuration Concept

With a final span configuration defined, the design-build team went to work to determine feasible precast shapes to support the three spans. The design team first explored a continuous precast, post-tensioned, spliced concrete girder. With a 240-foot center span and 120-foot end spans, the span ratio of 2:1 would not economically or geometrically accommodate making the bridge continuous for live load. In addition, the vertical clearance required by the railroad, coupled with the profile grade tie-in elevation at the existing Cross Street on the east approach, required relatively shallow superstructure depths for the entire east approach span, and would not allow for a gradual superstructure depth transition in order to effectively establish continuity over the pier. Committed to a precast concrete solution, the design team turned their efforts toward three simple spans. Given the magnitude of the center span, the design-build team immediately went to work on preliminary design.

Establishing the capabilities of the precast fabricator was a critical first step. J.P. Carrara's maximum crane capacity at the precast plant is 95 tons and their casting plant configuration can accommodate up to a 10-foot tall girder. J.P. Carrara already owned forms for the NEBT girders; therefore, this would be an economical girder shape to fabricate. With the precast girder parameters defined for fabrication and preliminary design, the team reached out to Corven Engineering, a nationally renowned specialist in post-tensioning construction, for a due diligence review. Corven conducted a review of the proposed bridge configuration and agreed that it was the most appropriate given the site and fabrication constraints. Corven also reviewed the preliminary design parameters and agreed that the proposed girder height of approximately 10-feet was within acceptable design limits. As a final check, Kubricky and Carrara again reviewed the preliminary design to determine risks associated with the project schedule and project budget.

With a viable bridge layout in-hand, the team presented the configuration to the Bridge Committee for approval. From there, the team and the committee presented the layout to the Town Selectboard for final approval, and it was endorsed without exception.

PRELIMINARY SUBSTRUCTURE DESIGN

As the preliminary superstructure design was progressing, the team simultaneously, coordinated with the Bridge Committee to develop pier concepts and aesthetic features. Several pier configurations were considered: column bents, wall piers with voided recesses to provide a "window" through the pier, solid wall piers with various arched and vertical recesses, and flared piers. The Town challenged the team to develop a pier that would be unique in its own right and be true to itself–a concrete pier with its own historic significance.

Cross Street Bridge Abutment

Brooklyn Bridge Abutment

Victor Nuovo, a member of the Bridge Committee and professor emeritus of philosophy at Middlebury College, was a proponent of creating a pier with unique character. He presented photos of a few historic bridges, the Brooklyn Bridge in particular, citing its distinctive visual appeal. These photos provided the initial inspiration for the piers, and from those initial ideas the team developed a pier concept with telescoping octagonal-shaped end caps, along with two full-height vertical recesses centered on each pier face. The features fit seamlessly with the height-to-width ratio of the piers and visually anchored the massive center span. Extending the ends of the piers beyond the superstructure fascia, and continuing to the pier ends above the bridge seats proved to be an effective way of shielding the difference in superstructure depth, which stepped at the pier from a 42-inch deep box beam end span to a 10-foot deep center span NEBT. The pier "end cap" also served to visually break up the sight line along the bridge fascia, thereby providing a graceful transition from the end span to the center span.

The Town also expressed an interest in visually marking the ends of the channel to motorists on the bridge in an effort to break up the long "viaduct" nature of the bridge and to add aesthetic interest. The Town originally proposed adding "spires" at the pier locations, which would extend above the roadway to mark the location of the channel. Once the pier shape was developed the debate was over how best to terminate the pier end caps. The design-build team eventually proposed adding overlooks at the pier locations. Since the Cross Street Bridge was intended to serve both motorists and pedestrians, the overlook concept was a natural way to provide pedestrians a place to rest and converse on the bridge while allowing others to pass by. Additionally, the overlooks break up the long superstructure and also serve as a distinguishing feature of the bridge.

FROM CONCEPTION TO REALITY: FINAL BRIDGE DESIGN

With approval of the Bridge Committee and overwhelming support and feedback from the Town's people, the bridge design concept proceeded to the final design phase. By March 2009, final bridge design was in full swing.

SUBSTRUCTURE DESIGN AND CONSTRUCTION

The design-build team immediately kicked-off the final design phase of the project, beginning with foundations.

Preliminary bridge borings were taken as part of an engineering feasibility study that had been conducted prior to selection of the design-build team. These select borings were used to develop preliminary foundation concepts in order to project which types of foundations would be suitable at each substructure location. The preliminary geotechnical evaluation suggested that the substructure units on the west side of the Otter Creek would be best supported on piles. The east side required more in-depth discussions due to the presence of a seven to 10 foot deep layer of silt and organic matter on top of very dense glacial till that was thought to be unsuitable for driving piles.

Once the final bridge layout was approved, the team initiated a final subsurface exploration and evaluation program at each proposed substructure location. At the same time, the team began a series of initial coordination meetings between the contractor, geotechnical consultant, and the design engineers to prioritize the design schedule. The team broke-down the bridge components into discrete construction document packages in order to meet the contractor's preferred order of construction sequence.

Anticipating that the west abutment and west pier would be founded on piles, the contractor preferred to begin construction there. This decision was aided by the fact that access to the east pier location required a formal Railroad Agreement between the Railroad, the State of Vermont, and the contractor in order to construct the pier within railroad right-of-way, and a superstructure over the railroad corridor. The layout and clearance envelope was subject to Railroad approval prior to the start of construction on the east side.

With the conceptual pier design approved in March 2009 and the ground breaking ceremony scheduled for April 14, 2009, the team worked quickly to produce construction documents for the west pier foundation.

As is common for most design-build projects, the substructure is typically designed and constructed prior to final design of the superstructure. The final bridge typical section had been approved as part of the conceptual design phase, which called for two, 11-foot travel lanes, 4-foot shoulders, 6-foot sidewalks on each side, and three rail anodized aluminum bridge rail with concrete pilasters, for a total out-to-out bridge width of 44-feet 8-inches. The spans were set at 120-feet, 240-feet, and 120-feet. With these criteria and the preliminary superstructure design, the preliminary superstructure dead and live loads were calculated and used in the final design of the substructure units.

Horizontal loads on the pier were minimized and distributed evenly to each pier by fixing the end spans at the abutments and by releasing both ends of the center span, thereby allowing the longitudinal breaking, thermal, and shrinkage forces to be distributed evenly between both piers (“expansion” style elastomeric bearings were used on each end of the center span, and over the piers on the end spans). Lateral superstructure earthquake loads are designed to be transmitted to the piers via cast-in-place “keeper blocks” that were built into each pier bridge seat.

West Pier

Due to the accelerated construction schedule and the quick turnaround required between approval of the conceptual bridge design and the project groundbreaking, the first construction document deliverable was the west pier foundation. This allowed the contractor to order steel h-piles and reinforcing steel for the footing prior to releasing construction documents for the intricate pier stem. Since the contractor was to begin pile installation at the west pier, for efficiency he chose to immediately follow with pile installation at the west abutment.

The west pier pile group consists of 30 HP 14x89 piles driven to bedrock, arranged in three rows of 10 vertical piles, each pile approximately 40-feet long. The geotechnical engineer determined that battered piles would not be required given the design loading.

West Abutment

The west abutment pile group consists of a single row of nine vertical HP14x89 piles driven to bedrock, each pile approximately 60-feet long. The pile group was designed to support a continuous stub abutment cap perched atop a wrap-around Mechanically Stabilized Earth (MSE) wall bridge approach. The abutment pile group layout construction documents were broken-out in similar fashion to the west pier foundation in order to allow the contractor to continue pile driving operations prior to the completion of the final abutment cap design. The piles extended down through the MSE engineered fill, through a layer of unclassified fill, into glacial till and ultimately set-up on bedrock. The geotechnical engineer was concerned that the unclassified fill would be susceptible to settlement, mostly during construction of the MSE wall, and since the piles had to be driven prior to construction of the MSE wall, the team needed to isolate the piles from potential down-drag induced by any settlement. This was accomplished by encasing the piles in a 24-inch diameter smooth-wall High Density Polyethylene (HDPE) sleeve that was filled with sand prior to casting the abutment cap.

The abutments were designed to accommodate the longitudinal loads transmitted to them through the fixed bearings. Since the west abutment single row of h-piles were too flexible to resist the longitudinal loads (these loads were not resisted at the piers as the beam ends were placed on expansion bearings over the piers) the loads were resisted via two layers of MSE straps spaced at one foot fastened to the abutment backwall. The straps resist the longitudinal loads traveling away from the abutment (toward the pier). Soil resistance against the cap and backwall was used to resist loads toward the abutment.

East Pier

The east pier foundation was initially anticipated to utilize drilled shafts due to 100+ blow count glacial till under a 10-foot layer of loose silt and alluvial fill material. The contractor preferred to use steel h-pile foundations as he could utilize his own labor force instead of hiring a specialty contractor, however, the design team was concerned that the piles would reach refusal without achieving the 10-foot minimum embedment depth into the glacial till. The depth of the loose alluvial fill layer was too deep to consider over-excavating down to the top of the glacial till layer. Over-excavating would require extensive dewatering and cofferdams capable of supporting railroad live load.

The contractor proposed an experimental “test pile” program to evaluate drivability at the east pier. Dynamic pile load tests were completed on each test pile with re-strike in order to confirm proper bearing had been achieved. The test pile program was successful and h-piles were used at the east pier en lieu of drilled shafts resulting in significant project savings.

East Abutment

Upon completion of the east pier stem, the focus turned to the east abutment which is a traditional spread footing abutment with u-back wingwalls. Dense glacial till was only four to seven feet below the proposed bottom of footing elevation and with the water table well below bottom of footing, the contractor elected to over excavate the unsuitable overburden material and replace it with a layer of engineered structural backfill.

Mechanically Stabilized Earth Wall

While the east abutment was being constructed, a second crew began construction on the west abutment MSE wall. The construction of the west abutment MSE wall was relatively routine, with the exception of localized over-excavation required to remove pockets of unsuitable organic matter that were found during a series of shallow supplemental field borings taken throughout the footprint of MSE wall. The uncontrolled nature of the fill made it imperative that the wall be able to accommodate minor amounts of differential settlement.

SUPERSTRUCTURE DESIGN AND CONSTRUCTION

The keystone of the project was the design and construction of the 240-foot precast, post-tensioned, spliced concrete girder center span. A simple span of this size and type had never been constructed before, and at nearly 10-feet tall, it was also the tallest precast NEBT girder ever constructed in the northeast.

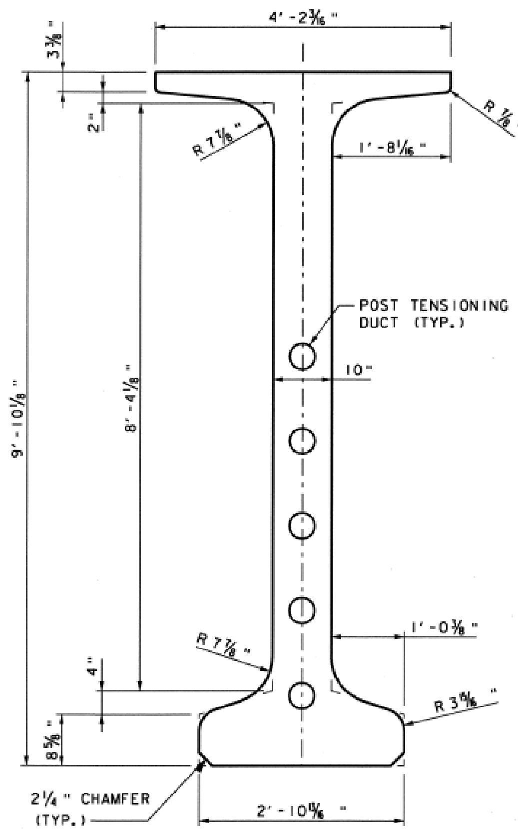
New England Bulb Tee Girders

In order to complete final design of the NEBT Girders, VHB teamed with Corven Engineering, post-tensioning design specialists, during final design of the record breaking span. Corven Engineering was initially brought in to provide a peer review of the design concept, and was ultimately engaged to provide final design, specification, and construction support during fabrication, erecion, and post-tensioning of the span.

Close coordination was required between J.P. Carrara, the precast fabricators, the contractor, and the design team in order to meet the tight schedule and stay on budget for both design and construction.

J.P. Carrara had three initial requirements crucial to the success of fabrication: the girder had to be less than 10-feet tall in order to be able to pick the girder out of the casting bed and load it onto the transport vehicles; the pick weight of each of the girders segments had to be less than 95 tons, the maximum capacity of the cranes in the fabrication plant; and to achieve economical fabrication costs, the design team needed to utilize the NEBT top and bottom flange configuration and configure the girder segment geometry in a way that was compatible with their fabrication beds.

The girder weight and geometry parameters pushed the design capabilities of the girder shape to the absolute maximum of its potential. The girder geometry was modified and refined through a series of intermittent reviews by the design team and the fabricator. Everything from girder height to flange widths to web width was scrutinized by the designers and fabricators. The final geometry of the girder resulted in a modified NEBT shape with a height of 9.84-feet (3000mm), a widened 10-inch web, a 34.9-inch bottom flange width, and a 48.2" top flange width.



NEBT Typical Section

One of the most significant challenges posed to the design team was the location of the girder splices. From a fabrication and transportation perspective, the girders had to be fabricated in three segments. Preferably the splices would have been located as far from the middle of the span as possible, in order to reduce the applied stress on the splice. The ideal location for the splice was at the quarter-point of the span, or 60-feet from the centerlines of bearing. However, at 1,700 pounds per linear foot the center segment of each girder line would weigh over 100 tons and would be beyond the maximum capacity of the precast plant cranes.

Therefore the final splices were located 65 feet from each pier, making the center segment a total of 108-feet long (accounting for a two-foot splice width), yielding a weight of 92-tons. Each end segment weighed approximately 66-tons, including the massive eight-foot long end blocks.

Each girder line required five post-tensioning tendons. The top two tendons consist of 19 0.6-inch diameter 270 ksi low-relaxation strands, and each tendon required approximately 835 kips of jacking force. The three lower tendons consist of 22 0.6-inch diameter strands, requiring approximately 967 kip of jacking force per tendon. The post-tensioning duct system selected for use in the girders consisted of corrugated polypropylene plastic ducts, which facilitated quick tendon installation, increased duct durability, and enhanced the overall corrosion protection of the tendon.

NEBT End Block Reinforcing

The high post-tensioning anchorage stresses at the end of the girders required heavily reinforced end blocks, the design of which demanded additional coordination and modification between the designers and fabricators. Bar size, spacing, and placement tolerance considerations were of critical importance to allow ample concrete between the reinforcing. Through a series of design reviews and interactive comment periods, the team swiftly produced a design acceptable to the fabricator.

The balance between fabrication parameters, efficiency, economics, and design performance requirements meant that the design team had to push the envelope by using high performance concrete with a 28-day compressive strength of 10,000 psi. Initially the team was concerned with the ability to place such high-performance concrete in large quantities while achieving proper consolidation in highly congested areas such as the end blocks. The solution was a self-consolidating concrete design mix. The design team requested trial batches to demonstrate the ability to produce a consistent mix with the proper design capabilities. A rigorous quality control program was employed by the fabricator, with independent quality assurance testing, and additional oversight from concrete admixture representatives throughout the mix design development and into the production fabrication process.

The concrete results were incredibly consistent throughout. Proper design strength was achieved in 7-10 days, while the proper release strength was achieved in less than 48 hours.

The fabricator's casting bed was 270-feet long, which was ideal for casting one entire girder line at a time. Five total casting runs were required (one for each

NEBT Casting Bed

girder line). With a turnover rate of just over a week between castings it took approximately a month and a half to fabricate all five girder lines.

NEBT Girder Transport

Following fabrication, the next challenge for the design-build team became the transportation of the girders from the precast plant through downtown Middlebury to the project site. Although only a five mile trip, the trucks would have to negotiate tight turns and narrow streets through town. The transport operation had to be carefully planned and the timing had to be coordinated for certain times of day to avoid long delays for the traveling public.

NEBT Girder Erection

Girders were erected starting at the east abutment. As each east 65-foot end girder segment arrived onsite they were hoisted into place with one end being set on the east pier and the other on a temporary pier in the channel of Otter Creek. A single 350-ton Manitowoc crane was used to erect the segments. Following the placement of the five east end segments, the crane was moved to a temporary platform that had been constructed in the center of Otter Creek. The middle segments of the center span were then delivered to the west shore of Otter Creek and as the 108-foot segments arrived, they were hoisted off the transport truck and set into place on two temporary piers. Erection of the 65-foot west end segments followed in a similar manner as the east.

NEBT Field Splice

Two-foot field closure splices, as well as permanent concrete diaphragms, were cast using the same 10,000 psi self-consolidating concrete mix as the girders. The close proximity of the concrete plant to the project site made it possible to use such a high-strength mix without compromising consistency. One challenge during construction was that the splices and diaphragms had to be cast during the winter months, requiring heated curing. The contractor addressed heated curing by threading a two-inch diameter tube with glycol circulating at 180 degrees around the forms of each splice and diaphragm and covering them with thermal blankets. Continuous recording thermal sensors were strategically placed around each concrete placement to monitor the curing temperature. The sensors were monitored regularly so that adjustments could be made as necessary.

NEBT Post Tensioning

The 240-foot center span was post-tensioned in January 2010. Despite the sub-freezing temperatures of Vermont, the weather did not significantly slow stressing operations. The crew installed and tensioned nearly 24-miles of post-tensioning strand in approximately three weeks. Upon completion of the stressing operation, the girders lifted off of their temporary supports by approximately 1 inch. The temporary supports were then removed from the channel, and the Otter Creek was finally traversed unobstructed.

The weather did play a role in the progress of the bridge construction, however. Since the tendon stressing operation was completed in mid-winter, it was too cold to initiate grouting of the tendons. The ends of the girders had to be accessible in order to grout, therefore the end spans could not be erected until the grouting was completed. For the interim time period between stressing operations and grouting, the post tensioning ducts were charged with a corrosion inhibitor to protect the exposed strands. The strands were inspected several times to ensure their integrity. In mid-April 2010, as soon as the temperature allowed, the inhibitor was blown from the ducts and the grouting operation proceeded. At the completion of grouting, the end block pour backs were installed and the design-build team turned their focus to the box beam end spans.

Box Beam End Spans

The 120-foot long, 42-inch deep box beams for the end spans were fabricated during the winter months of 2009-2010. Similar to the center span, the box beams also utilized a self-consolidating concrete mix with a required design 28-day compressive strength of the 8,000 psi. Each box beam required 56 0.6-inch diameter 270 ksi low-relaxation prestressing strands, 50 straight strands in the bottom flange, and six straight strands in the top flange. The large number of strands in the box beams created high stress concentrations in the end blocks, and therefore the prestressing release strength was required to be 6,000 psi.

In a similar fashion as the NEBT girders, the box beams had to be carefully transported through the narrow village streets of downtown Middlebury. Ten box beams had to be delivered to the west abutment and ten box beams had to be delivered to the east abutment. Once on-site, the box beams were picked directly from the transport trailers and set in place spanning between the abutment and pier.

The erection of the box beams on the west side was completed in a conventional manner with two cranes. Each crane picked an end of the beam and coordinated their movements to set the beam into place. Following erection of all 10 box beams, the cranes were transported to the east side of the bridge. The erection of the box beams on the east side had to be a carefully coordinated process. The east abutment is perched at the top of a 3:1 spill slope which extends to the railroad at its base. The location of the railroad and the length of the spill slope limited the contractor's available staging locations for the cranes. In an innovative erection sequence, the contractor elected to utilize a series of three cranes in a choreographed box beam hand-off.

Erecting the East Box Beams

The first crane was placed directly behind the east abutment; the second crane was located at the base of the spill slope, to the east of the railroad, and a third crane adjacent to the pier. The second crane began by picking the west end of the box beam off of the transport dolly by using a sling instead of the lifting loops embedded in the end of the box beam. The transport backed up towards the pier while the crane rotated to the west, walking the end of the beam towards the pier. Once the east end of the box beam was in reach of the crane behind the abutment, the crane finally lifted the east end of the box beam off the transport. At this point, the third crane was in range of the west end of the box beam. This crane engaged lifting loops, which then relieved the middle crane from duty. Finally, the first and the third crane would rotate the box beam to the abutment and the pier respectively and place the beam on the supports. All 20 box beams were successfully erected in less than 3 days.

Upon completion of box beam erection and grouting, the construction crew immediately focused on forming and placing the concrete bridge deck. It was decided to place the deck in one continuous operation starting at the west end (the low side) and proceeding to the east. The center span deck slab consists of an eight-inch thick slab with a 28-day compressive strength of 5,000 psi. Each of the two end spans has five-inch minimum thick topping slabs with a required 28-day compressive strength of 4,000 psi. To utilize a single concrete mix design during the continuous deck placement operation, the contractor opted to use the 5,000 psi concrete mix for each of the three spans. Once the deck was cured, the six foot concrete sidewalks were constructed. Between the curbs, torch-applied sheet membrane waterproofing was installed and the deck was paved with three inches of bituminous concrete.

With the bridge deck complete, one of the more defining features of the bridge was constructed: the overlooks. Four 11-foot wide octagonal shaped overlooks were constructed; one perched on top of each end of each pier, reflecting the shape of the pier ends. As the overlooks cured, the precast concrete pilasters and three-rail anodized aluminum bridge railing was installed.

Pier Overlook

CONCLUSION

An innovative approach to funding, cutting edge design, and aesthetic detailing, make the Cross Street Bridge truly one of a kind. The use of precast bridge materials saved design and construction time and brought another level of efficiency to this fast-paced design-build project. Due to the close proximity of the precast plant; the entire design-build team was able to interact face to face on a daily basis.

From initial concept through final design, the Cross Street Bridge was a welcome addition to its unique New England Town. On October 30, 2010 the bridge opened with a daylong celebration. The town's people packed the bridge deck for a parade, speeches, and a local band performing well into the night. When the party ended and the bridge deck was cleared, traffic streamed across 240-foot precast, post-tensioned, spliced concrete girder center span. A simple span of this size and type had never been constructed before in the U.S. Precast concrete had realized a new frontier.

The Completed Cross Street Bridge