RAPID BRIDGE CONSTRUCTION IN NEW HAMPSHIRE

Peter E. Stamnas, PE, NH Department of Transportation, Concord, NH
Mark D. Whittemore, PE, NH Department of Transportation, Concord, NH

ABSTRACT

Minimizing construction related traffic delays and improving work zone safety on future projects is the main reason for the New Hampshire Department of Transportation's (NHDOT) foray into rapid construction of medium span bridges. The NHDOT received Innovative Bridge Research and Construction (IBRC) funds to pursue project innovations that could significantly affect methods of design, detailing and construction of bridges in the future.

The proposed town bridge replacement project in Epping, NH will replace two existing spans carrying Mill St. over the Lamprey River with a 115'-0" single span butted box beam superstructure on precast concrete substructures. The contract requires the bridge to be assembled and ready for traffic in two weeks.

This paper will focus on substructure details and how project schedule, design, specifications and contractual arrangements for a conventional bridge replacement project are impacted by specifying rapid bridge construction.

Key Words: New Hampshire, Rapid Construction, High Performance, Concrete, HPC, Precast Substructure, IBRC

INTRODUCTION

The New Hampshire Department of Transportation (NHDOT) has taken a lead role in promoting the benefits of the use of High Performance Concrete (HPC) in bridges. This initiative has improved the quality of concrete used in bridge construction and extended the life of cast-in-place concrete decks and other precast concrete bridge members. The long-term benefits of HPC will be realized as the life cycle costs of bridge replacement projects are reduced.

During the past several years, NHDOT has pursued an initiative that combines HPC with the use of rapid bridge construction techniques. This effort builds upon the long-term benefits of HPC material innovations and refines the construction process to address the always-present concerns with construction related traffic delays and worker safety in construction zones. NHDOT believes that incorporating rapid construction techniques into bridge construction practices may provide the answer to these significant concerns.

A "Fast Track" approach that integrates the use of HPC and precast/prestressed concrete components is being utilized on a NHDOT project as a means to mitigate traffic delays and improve worker safety in construction zones. The Federal Highway Administration's (FHWA) Innovative Bridge Research and Construction (IBRC) program has provided funding for the replacement of a Town owned bridge in Epping, New Hampshire. The existing 120-foot long crossing will be replaced by a fully precast concrete structure. The time allowed in the contract to assemble the new bridge and open it to traffic has been limited to a two-week period.

THE PROJECT SITE

The Mill St crossing in Epping, NH was chosen as the first site to incorporate fast track construction methods. This crossing provides access to a neighborhood and the traffic volumes are very low (AADT < 400). One of the reasons this site was chosen was to minimize the overall risk of using a newly developed, untested, substructure system. The NHDOT wanted to ensure the new system worked before it was incorporated into a high traffic volume, high-risk site where it <u>had</u> to work.

The design issues at this site are considered challenging but fairly typical of New Hampshire's bridge projects. The existing 120-foot long crossing carries Mill St over the Lamprey River. It is comprised of two, 30-foot long simple spans separated by a 60-foot long center pier/causeway. The south abutment is founded on shallow sloping ledge and the north abutment is founded on a granular material. Concerns with water control further complicate the construction of the new foundations.

THE SOLUTION

The new structure utilizes a 115-foot long adjacent box beam superstructure to span the river (See Figure 1). The typical span range of the 3'-0" deep superstructure was extended with the use of HPC and 0.6" diameter strand. Full depth shear keys and two rows of ½" diameter strand, used as transverse post-tensioning at six locations along the beam, are detailed to complete the connection between the units (See Figure 2). The riding surface is comprised of waterproofing membrane and a bituminous pavement overlay. The superstructure is supported by full height, cantilevered, precast concrete abutments founded on precast concrete spread footings.

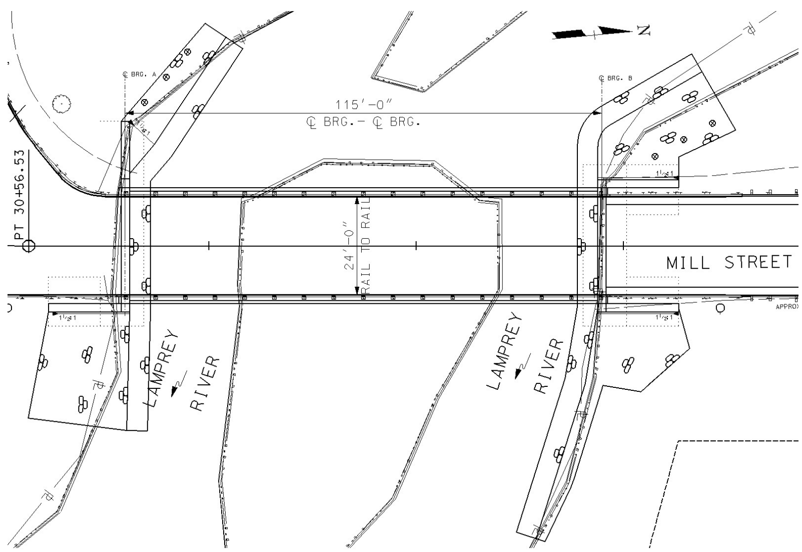

Figure 1. General Plan

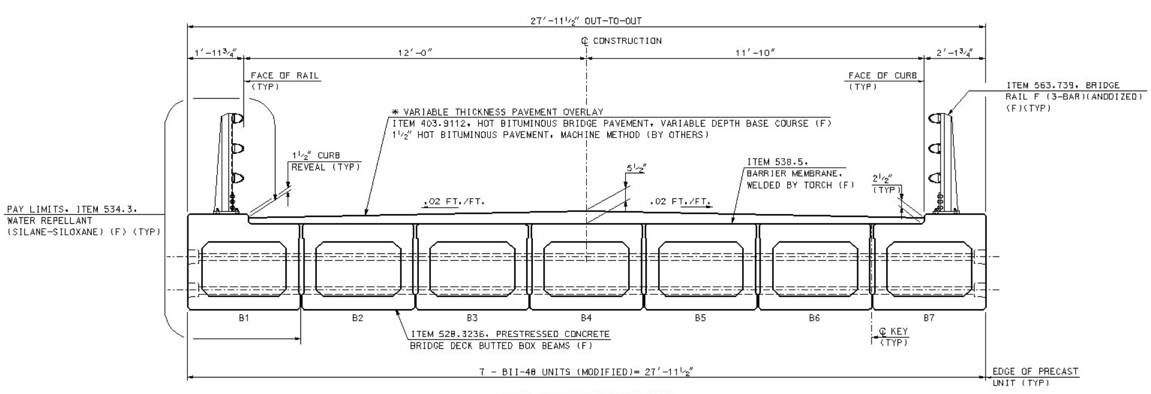

Figure 2. Typical Deck Section

Precast Substructure System Development

Over the years cast-in-place (c-i-p) concrete substructures have proven to be very versatile. They can adapt to varying site conditions with ease, construction tolerance abounds and overall familiarity with c-i-p concrete is universal in both design and construction. However, c-i-p substructures are time consuming to construct and the NHDOT feels the quality of workmanship has deteriorated over the years. The NHDOT wanted the new substructure system to emulate the desirable aspects associated with c-i-p construction and improve upon the less desirable aspects. Precast concrete substructures were the answer.

A team was assembled to develop the new substructure system. This team was comprised of NHDOT staff, Dr. Charles Goodspeed of the University of New Hampshire, the Precast/Prestressed Concrete Institute – Northeast Region Technical Committee (PCINE), David Hall from FHWA, and local general bridge contractors and precasters.

The main thrust in the development of the new system was to speed up construction, creating a complete bridge system (See Figure 3), capable of spanning more than 115 feet and one that could be constructed in a few days instead of a few months.

Early on, the team identified a number of specific issues and detailing requirements that would have to be addressed to meet this objective.

- Create a totally precast solution
- Provide detailing to minimize shipping and handling difficulties
- Accommodate tolerances in fabrication and construction
- Provide effective, durable, cost effective connection details
- Provide a means for efficient grade adjustments of the footings
- Provide a sound unified bearing surface with adequate sliding resistance

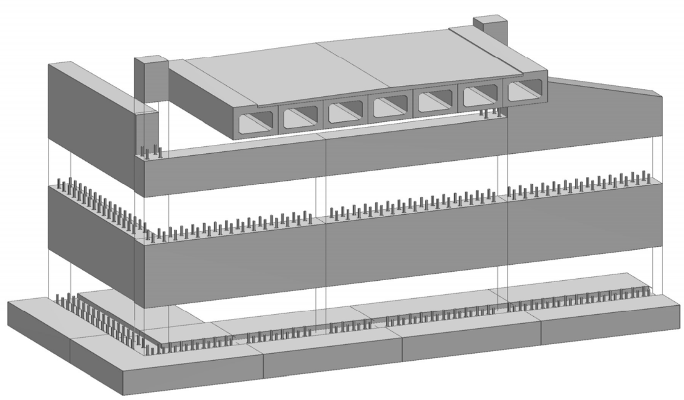

Figure 3. Totally Precast Solution

The following details were developed and used on the contract drawings. The associated narratives provide additional insight to the challenges and the solutions.

Full height cantilevered abutments on spread footings (See Figures 4 & 5)***:*** This substructure type is used on a significant percentage of NHDOT bridge replacement projects. The c-i-p version would require six separate concrete placements and approximately one month to construct. The precast alternative can be completed in less than two days.

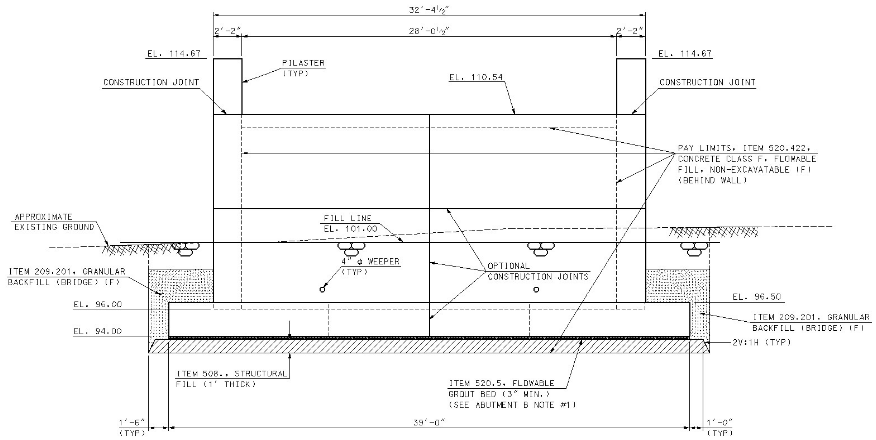

Figure 4. Abutment Elevation

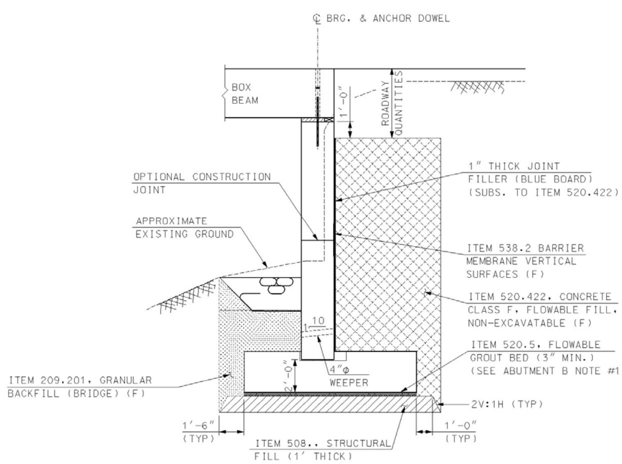

Figure 5. Abutment Section

Flowable Grout Bed (See Figure 5)***:*** The strength and air requirements of the flowable grout bed specified for use on this project conform to the typical specification for footing concrete. It is placed through grout tubes in the footing that are spaced at five-foot intervals. A minimum compressive strength required to resist full design loading (approximately 250 psi) can easily be achieved overnight. This 3" minimum thickness grout bed provides a sound, unified, bearing surface that also acts as the "glue" between the bearing materials and the roughened bottom surface of the precast footing.

Precast Footings: The use of precast footings will accelerate construction. The footing is divided into individual elements to facilitate shipping and handling. The precaster can standardize element sizes to reduce fabrication costs. Templates used during fabrication will ensure a proper fit between the stem and footing elements.

Leveling Screws (See Figure 6)***:*** A simple cost-effective detail provides the means to make fine adjustments in setting the footings to proper grade without the need of a crane or other heavy equipment. The leveling screws are installed near the corners of all footing elements. All adjustments are made by hand from the top of the footing.

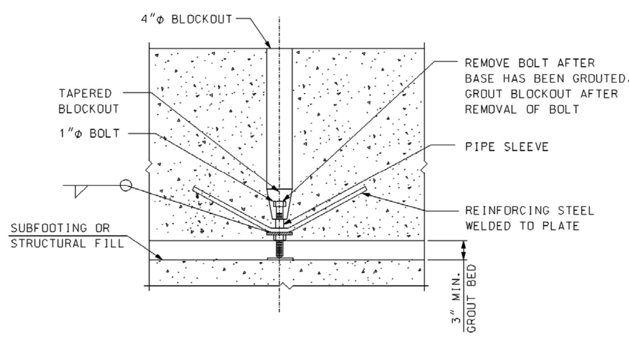

Figure 6. Leveling Screw

Grouted Shear Keys (See Figures 7 & 8)***:*** All vertical joints between precast elements utilize grouted shear keys. These keys not only assist in the development of a unified element but also provide a means to make allowances for fabrication and construction tolerances.

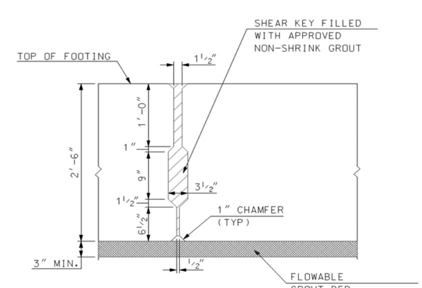

Figure 7. Footing Joint Detail

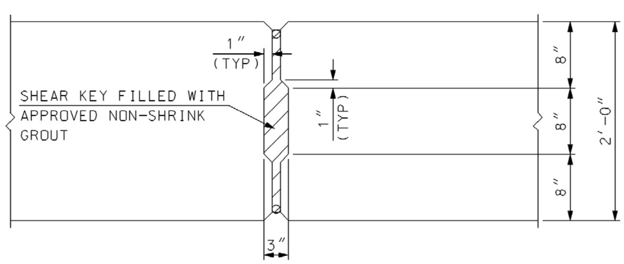

Figure 8. Stem Key Detail

***Precast Stems*:** The precast stems share the same proportions, and are reinforced similar, to their c-i-p counterparts. Horizontal joints are allowed in the stem to facilitate shipping and handling (See Figures 4 & 9). Full moment connections are provided at these joints as well as at the stem-footing interface (See Figures 9 & 10).

Full Moment Connection (See Figures 9 & 10)***:*** The moment connection is provided by the use of grouted splicers. Splicers are cast into the front and back face of the upper element. These splicers accept reinforcement extending from the bottom element. High strength grout is pumped into the splicer ports to complete the connection. The splicers are considered to be like any mechanical splice used in c-i-p construction. They are required to exceed 125% of the specified strength of the bar being spliced. The 1" minimum horizontal joint between the upper and lower stem elements is filled with a high-strength, non-shrink grout. This grout provides a durable protective layer to the structural connection.

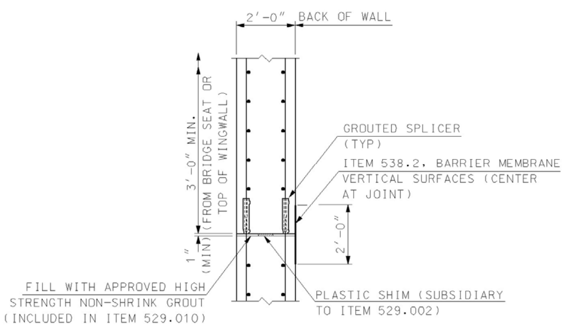

Figure 9. Stem Joint Detail

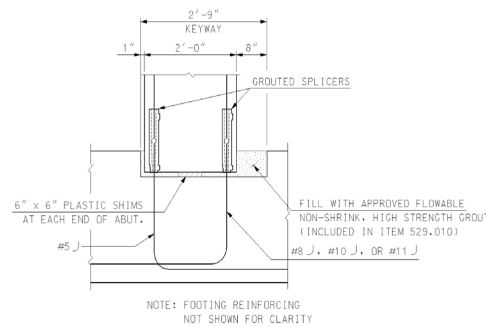

Figure 10. Stem/Footing Joint Detail

Bridge System Specifications & Contractual Arrangements

One of the outcomes of NHDOT's HPC initiative has been the move away from the use of prescriptive specifications for concrete to specifications that are performance-based. This change has improved the overall quality of the concrete used on bridge projects, has increased the amount of work to be completed by the supplier and holds the contractor responsible for the quality of the end product. This change requires the contractor and supplier to become more actively involved in the solution.

A similar process was introduced into this rapid bridge replacement project on a more global level. A bridge delivery concept that fits somewhere between a traditional design-bid-build delivery and a design-build delivery was developed. This concept keeps control of the design in the hands of the Department and leaves the means and methods of bridge assembly in the hands of the contractor and precaster. The contractor, together with the precaster, determines where joints within the substructure are introduced and how the precast bridge elements will be assembled.

To assist in this effort, standard details are provided in the plans to address various types of joints. All horizontal joints in stems are full moment connections created with grouted splicers. All vertical joints in stems and footing elements require the use of grouted shear keys. The contractor is responsible for developing an assembly plan that will minimize the overall costs of the operation and also minimize the time to construct the bridge. This plan will consider fabrication, transportation and component handling and assembly requirements to provide the best-fit solution for their overall operation. This assembly plan is submitted for approval to ensure conformance with the stated requirements in the contract.

Costs Associated With Accelerated Construction

This project is partially funded by an IBRC grant. The State and Town will share all costs above and beyond the grant amount. The budget for the project is approximately 1 million dollars.

The original project concept included two separate challenges:

1) Limit the road closure to 30 days
2) Assemble the bridge in less than 14 days

The first challenge required an approximate 80% reduction in the 5-month time frame it would normally take to construct a project of this scope. This required the contractor to carefully plan and schedule work for the entire project. This project-based goal incorporates all site-specific conditions into the equation.

The second challenge was introduced as the ultimate test for the new bridge system. The 14-day assembly window begins with the commencement of lifting operations to set the first precast element. This second challenge allows the Department to evaluate the effectiveness of the bridge system by removing all of the site-specific conditions from the equation. The 14-day clock doesn't start until after the site is prepared.

Two separate incentive/disincentive clauses were included in this proposal, one for each challenge described above. The first clause awarded the contractor $1,500 per day for early completion and penalized the contractor the same amount for a construction duration in excess of thirty days. The second clause awarded the contractor $5,000 per day for early completion and penalized the contractor the same amount for a construction duration in excess of fourteen days.

The project was originally advertised for construction in September of 2003. The low bid was 1.4 million dollars, well above the 1 million dollars budgeted for the project. The bid subsequently was not awarded.

The Department made several modifications to the contract in an effort to reduce costs, most significantly through eliminating the 30-day road closure window. The 14-day bridge assembly window and its incentive/disincentive clause remained in the contract. The modified project was re-advertised for construction in December of 2003. The low bid of $1,047,000 was within budget. The project was awarded to R.M. Piper Construction of Plymouth, New Hampshire. The Contractor chose J. P. Carrara of Middlebury, Vermont to supply the precast bridge elements.

Accelerated construction introduces risks to the contractor that will impact the price of a bridge replacement project. The factors that are included in a price comparison are extremely important in ultimately determining the feasibility of the decision to accelerate the completion of the project. The cost increase might seem unjustified if the costs factors are limited to a comparison between bridge items only. However, a valid comparison must also include costs associated with traffic control and traffic delays. Some consideration must also be given to the improved quality associated with the precast concrete element.

Detouring traffic around a construction site is a very cost effective way to address traffic control. However, the duration required to construct a bridge with conventional methods limits the feasibility of this alternative. This leaves the designer with the more expensive solutions - phased construction and temporary bridges with on-site detours. The costs for a temporary bridge and the associated approach work are usually directly associated with specific items that make them fairly easy to quantify. Costs for phased construction are not as easily quantified but it is estimated that they can increase typical bridge costs by 20 to 30 percent or more depending on traffic volumes at the site. High volume roads utilizing lane shifts, delay traffic and create a hazardous environment for construction workers. Costs associated with these real issues are also very difficult to quantify. An accelerated timeline may eliminate the need for expensive on-site traffic control by making an off-site detour more palatable to the user.

It is very difficult to compare total project costs between projects utilizing conventional timelines and those utilizing accelerated timelines. Each project site provides its own set of unique challenges. Overcoming each of these challenges comes at a price. In most cases, projects utilizing accelerated construction techniques will cost more to complete. The bridge cost on this project highlights this concern. The bridge specific cost removes most items that are site specific and provides a cost number that is more meaningful when comparing bridge costs for similar size crossings. All bridge items are evaluated and any considered site specific are removed from the list. The typical bridge cost for a bridge of this size in New Hampshire is 105 $/sf. The bridge costs for this project are 172 $/sf. This method of comparison thus shows a significant increase in bridge cost between a conventional and accelerated bridge construction project; in this specific case a 70% increase.

Some of this cost increase can be attributed to the new concepts being used. It is anticipated that prices will come down as the concepts become more commonplace and the contractors and precasters become more familiar with the details. The cost increase directly related to bridge items should be compared to the overall value the concept provides to the project as a whole, in order to determine whether the use of this concept is feasible for a particular site.

Changes In The Way We Think

Bridge engineers have become accustomed to providing the best possible solution to a problem. Cast-in-place concrete has been akin to that solution. The combination of a versatile medium and a crew of good carpenters can construct almost anything a bridge engineer can conceive of. Searching for that best skew or wing angle to help minimize inlet losses for the hydraulic solution; using batters and butterflied sections on cantilevered wings to minimize the amount of concrete that had to be placed; a jog in the backwall here, an acute angle there, create solutions to problems that on a micro level seem important, but when looking at the big picture become less important.

The use of precast concrete substructures may require the engineer to settle for something less than that ideal solution to a geometric problem on a bridge replacement project. The engineer must focus on ease of fabrication, repetition, and ease of assembly to create a cost effective, precast concrete solution. The following ideas should be considered when detailing a precast substructure for use on a bridge replacement project:

- The choice of available angles between abutment and wings should be limited to 30, 45, 65 and 90 degrees. Bridge skew angles should be minimized. In cases where they are unavoidable, the skew angle added to the wing angle should equal one of the available standard angles.

- Stem heights for abutments and wings should be detailed in 6" increments and site grading and appropriate choice of bottom of footing elevations should be used to fine tune the solution. The designer can detail the bearing seat to the nearest 1/8" as long as the bottom of footing elevation is established with the same precision.

- Batters on abutment and wing stems should be eliminated and the overall thickness of the stems should be minimized to reduce the overall weight of the element.

- Footing widths should be detailed in 6" increments and have a maximum width of 12' to minimize transportation difficulties.

- Alternative backfill materials should be considered. Flowable fill could be used instead of a granular backfill material. This material reduces the long-term earth pressure forces exerted on a wall but generates short-term hydrostatic pressures that must be accounted for in the design. A temporary support system could be introduced to resist the short-term hydrostatic loads allowing the reduction of the required main reinforcement provided in the stem and footing due to the reduced earth pressures. It should be noted that the temporary support system could cost as much or more than the amount saved in reinforcing materials in some instances.

- Construction access is very important. Precast substructure elements weighing on the order of 30 tons or more should be anticipated. Large cranes requiring an abundance of room to operate will be required to assemble the bridge components.

- Details at vertical joints between elements should be standardized. Grouted shear keys should be detailed for use between all abutting elements. Attention to shear key preparation, choice of grout material and grout installation is imperative.

- Standardization of details is a key element in accelerated construction; providing a solution that is cost effective, easy to construct and meets all of the stated requirements of the project.

SUMMARY & CONCLUSIONS

The NHDOT views the use of accelerated construction techniques in conjunction with high performance concrete as an important tool to reduce construction related traffic delays, improve work zone safety and improve the long term durability of bridges. The concept is not viewed as the "magic cure" for the ills of the infrastructure. Rather, it is seen as another "tool in the bag" for bridge engineers that can be used when the conditions are appropriate. The following items are offered as observations:

- ***The precast concrete substructure system detailed for use has promise.***
    - the system emulates the favorable aspects of c-i-p construction
        - utilizes standard design concepts
        - uses elements produced locally with readily available materials
        - easy to construct and assemble
        - durable when constructed properly
    - the system improves on the less favorable aspects of c-i-p construction
        - significantly reduces the time to construct the substructure
        - precast elements are constructed to tight tolerances
        - HPC provides a high quality solution.

- ***Accelerated construction will improve work zone safety.*** Partial use of the techniques may be the right answer in many instances. More often than not we tend to associate work zone safety with automobile traffic. However, work zone safety is also a significant issue near commuter rail lines. Precast substructures could be utilized on bridge projects crossing these lines. Train traffic at these sites usually limits the available construction windows, which can result in significant increases in the time to construct the substructures. The advantage of precast elements is that they can be readily assembled within the available construction window. Savings realized on items such as the reduced rental time for a temporary bridge and wasted labor to mobilize the construction crew around these windows, would compensate for the additional costs associated with the fabrication and delivery of precast elements.

- ***Precast elements can be used to address manpower limitations*** and might be the answer for contractors that struggle with the limited availability of experienced manpower. Aggressive construction schedules have been increasingly commonplace on NHDOT projects. These aggressive schedules require the contractor to mobilize two or more crews, working in parallel, to meet the completion schedule. Consequently, many smaller contractors may not be able to bid on a project of this nature. Accelerated construction techniques utilizing precast elements might offer more bidding opportunities for small contractors, thus increasing competition which could ultimately reduce construction costs.

- ***Accelerated construction will minimize the duration of construction related traffic delays on high volume roads.*** Online reconstruction of bridges on high volume roadways can extend the construction duration of a typical crossing into a second construction season. The impact of this extension on the user can be significant. Traffic delays translate into user costs that are difficult to quantify and usually aren't figured into the bottom line for project related costs. Consideration of user cost savings could offset the increased costs associated with accelerated construction.

- ***Expect a cost increase.*** Accelerated construction creates risks for the Contractor that will increase costs. The magnitude of the cost increase will vary from project to project and will be highly dependent on site specific conditions. As the risks to the contractor are reduced, project costs will also be reduced.

  It is very clear that the increased cost of bridge items due to accelerated construction techniques should be compared to the value they bring to the project as a whole. The value comparison must include potential cost savings associated with traffic control items and the reduction in life cycle costs of the bridge due to the improved quality of the precast concrete solution. The expected long-term benefits of the use of HPC in bridges are well documented but they have come at a price. The NHDOT views the introduction of precast concrete elements to bridge substructures in the same light.

- ***Are the grouted joints between precast elements the weak link?*** Grouted joints typically draw a significant amount of attention from bridge engineers. Deterioration of the joints can expose the structural components to the elements and reduce the lifespan of the entire system. It is very common for these joints to be viewed as a small piece of the overall construction effort by Contractors. As such, limited attention and care is used when preparing and grouting the joint. During construction, attention must be focused on these details. Shear keys must be sand blasted to remove any laitance that would inhibit bond. Grouts used to fill the joints must be mixed to the manufacturer's recommendations for them to be effective.

  Grouted shear keys in this substructure system should be viewed as a critical detail even though the exposure conditions for substructures in most environments are typically lower than those experienced by superstuctures. The lower exposure conditions do provide some comfort level to introducing a detail that can be problematic. Exposure conditions such as salt-water environments should always be considered before deciding whether to utilize precast concrete substructure elements with grouted shear keys.

- ***The most appropriate delivery concept may be to allow the substitution of precast substructure components for c-i-p elements.*** This concept has been incorporated into the NHDOT's standard practice with partial depth precast concrete deck panels used as stay-in-place forms. Experience has shown that prices tend to be higher than average when deck panels are specified, by the NHDOT, on a bridge deck replacement. However, the cost tends to be lower when the Contractor is interested in using them to address an issue critical to the successful completion of a project goal. The NHDOT current practice is to detail full-depth c-i-p decks on plans and also include, where appropriate, the option to substitute deck panels. The decision to use the deck panel option is made by the Contractor during the bid phase and can therefore be factored into the bid price.

  This same concept would be appropriate for other bridge elements. The typical c-i-p elements would be designed and detailed for use on the contract drawings. Standard details for emulating the c-i-p elements would also be included. The Department would set the completion date and the Contractor would decide what means and methods are required to complete the work on time. Similar to the previous example, the cost is factored into the bid price without limiting the potential solutions.

  The downside of this delivery concept is that the owner cannot take advantage of the potential savings in engineering and plan preparation costs. The substructure detailing on the Epping Rapid Bridge Replacement Project was reduced in half, from ten plan sheets to five. This was accomplished by detailing rebar in section only. All rebar elevations were eliminated as they would be completed by the precaster and included in the shop drawings. This concept also eliminated the work associated with rebar summary sheets for the design team. The Department's course of action on this issue will develop over time. A number of projects utilizing both delivery concepts will be constructed and the results of each evaluated before a decision is made.

The NHDOT views its first rapid bridge replacement project in Epping as a starting point for a concept that will be improved upon as more is learned through fabrication and construction of the Epping bridge during the summer of 2004. The ease of construction and the overall effectiveness of the details used on this project will be scrutinized and improved, as necessary, before they are included on another bridge replacement project. This project has provided a valuable learning experience to the NHDOT and all those involved in the design and construction effort. We look forward to confronting the challenges created by utilizing rapid bridge construction techniques on future projects.