

NEXT BEAMS – THE VALUE ENGINEERED WAY

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ABSTRACT:

In 2010 NJDOT issued a contract for the replacement of several structures along Route 3, a road that averages 130,000 vehicles per day. Working with the Contractor, the Precast Engineer developed a value engineering alternative to provide two NEXT beam bridges (the first for NJDOT) in lieu of the proposed prestressed box beam and I-beam bridges. This yielded a project cost savings of \$20,000, saved one construction week per bridge, improved worker safety, and eliminated the requirement for debris catch planks. These bridges have challenging geometries including vertical profiles, skewed abutments, multiple cross slope changes, level bearing pad requirements, and a varying bridge width from 170' to 174'. A number of project specific design features including bearing restraints, zero net tension, and a state specific live load pattern were required. With the introduction of a new beam system, several other bridge elements including the integral abutment pile system and deck overhang/barrier attachment required reevaluation. The redesign and shop drawing preparation met the construction schedule without delays.

This paper will discuss the benefits of NEXT beams on certain projects, and the challenges presented through value engineering and how they can be overcome through experience, coordination, and creative adaptability.

KEYWORDS: NEXT Beams, Value Engineering

INTRODUCTION

Northeast Extreme Tee (NEXT) Beams are gaining popularity not only in the region that is their namesake, but across the United States as well. States and Municipalities are eager to take advantage of their installation speed, durability, access for utilities, openness for inspections, and, of course, their cost effectiveness. One of the challenges that these authorities are presented with is implementing new technologies and products into a project, and sometimes the best avenue for this is through value engineering. In the Winter of 2010, under the direction of the Contractor, the Precast Engineer was tasked with the redesign of a proposed 56' Prestressed Concrete Box Beam bridge (Bridge #3) and 65' Prestressed Concrete I Beam bridge (Bridge #5) located on Route 3 in Clifton, NJ. This section of Route 3 averages 130,000 vehicles per day; thus construction was scheduled for completion in three stages, maintaining a minimum of three temporary traffic lanes in both the East and Westbound directions.

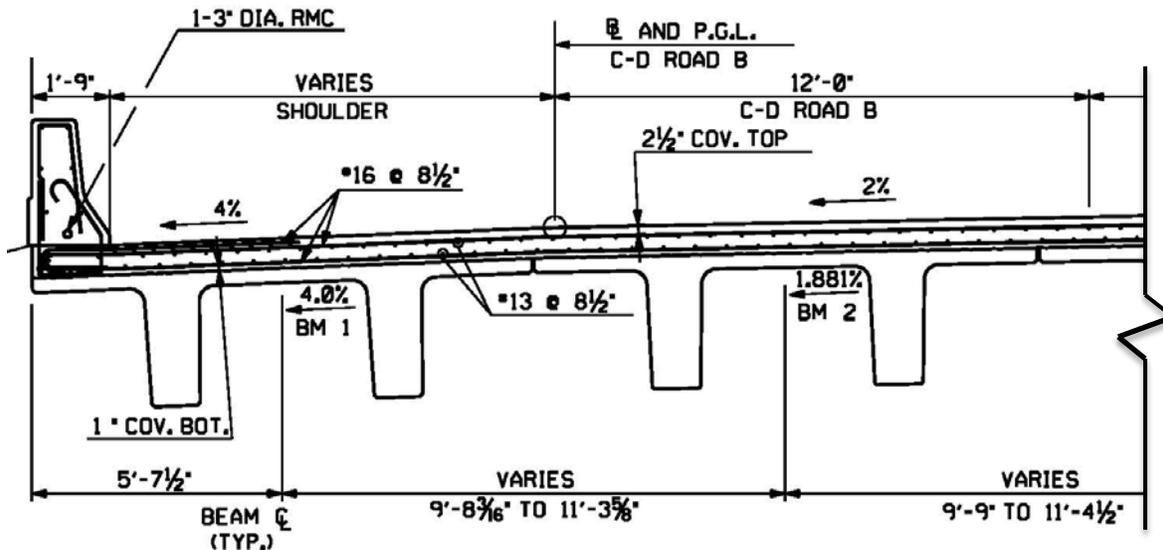


Figure 1 Bridge #5 Cross Section

Bridge #3 and Bridge #5, currently under their second phase of construction, are part of a much larger project for the reconstruction of 2.45 miles of Route 3. The full project includes the replacement/repair of 7 bridges, 205,000 square feet of retaining wall, noise barriers, and 19 overhead signs.

This large scale project had a construction schedule that allowed the Contractor and Precast Fabricator to investigate the potential for value engineering (VE) through the use of NEXT beams on two of the bridges. This study concluded that the NEXT beam alternatives provided benefits to both structures; by allowing the Contractor to delete the need for bottom deck formwork, construction speed increased by approximately one week per bridge and the superstructure system change yielded a project savings of \$20,000.

The challenges presented in updating the project design and documents from the original Box and I-beam types to NEXT beams did exist, but the Precast Engineer and project team worked diligently with the Engineer of Record (EOR) and NJDOT to incorporate



Photograph A: 65' Span NEXT Beam Construction Stage 1

the updated beams into the project design within 3 months of being assigned the VE task, meeting the construction schedule without delays. Implementing these beam changes included accounting for the baseline vertical profile, skewed abutments, multiple cross slope changes, bearing restraint requirements, and a bridge width that varied from 170' at the west abutment to 174' at the east abutment. The engineering of the beams was tailored to meet state specific requirements. And the VE design extended beyond the beams to include evaluating all bridge elements impacted by this change including bridge deck, abutments, and piles.

- Benefits of NEXT beams:
- A cost effective solution for bridges between 40 feet and 90 feet
 - Increased construction speed
 - Single cast precast/prestressed pieces
 - Utility access
 - Inspection access
 - No bottom deck form
 - Shallow superstructure section
 - Improved worker safety – no gaps between beams
 - Debris catch planks not required

Figure 2 Summary of NEXT beam benefits

This project represents the success of implementing a new bridge technology (NEXT beams) into a region through the process of value engineering. This paper will highlight the obstacles that the project faced and how they were resolved, hopefully aiding in the appropriate implementation of NEXT beams and providing foresight into managing a successful value engineering change. Due to the similarities between the bridges the majority of the paper focuses on Bridge #5, the 65' structure with integral abutments.

THE VALUE ENGINEERING PROCESS

As described in the introduction, these two bridges were not on the critical path of construction. Following the award of the project, the Precast Fabricator, who was experienced in the fabrication and applications of NEXT Beams, identified to the Contractor that there was potential savings in the usage of NEXT Beams in lieu of the Box Beams and I-Beams as originally quoted. The Contractor agreed this was a good opportunity for the project and coordinated with the Fabricator to develop a proposed value engineering item which was submitted to the Owner in September 2010. The Owner, NJDOT, and the Engineer of Record approved the concept VE item and notice to proceed was given to the Precast Fabricator and their independent Precast Engineer in November of 2010.

Following notice to proceed, the Precast Engineer began the fast-tracked VE design which involved a team of 5 engineers and technicians working on individual tasks with a coordinated approach. The design process was completed in three months, with the updated plan set completed in March of 2011. Coordination of review comments and 'approved' shop drawings were completed that Spring, with final VE approval given in June of 2011. The first NEXT beams were installed three months later, and Stage 1 construction was completed with prized efficiency.

GEOMETRY

The first step of the redesign involved defining a beam layout that fit with the roadway cross section (reference Figure 3). Stage locations did not align with the top of slab cross slope transition points. This did not present a challenge for the I-Beam system, but with the abutting flanges of the NEXT Beam system it confined layout possibilities and did not allow the beam widths to match the cross slope transition points. A CADD model was

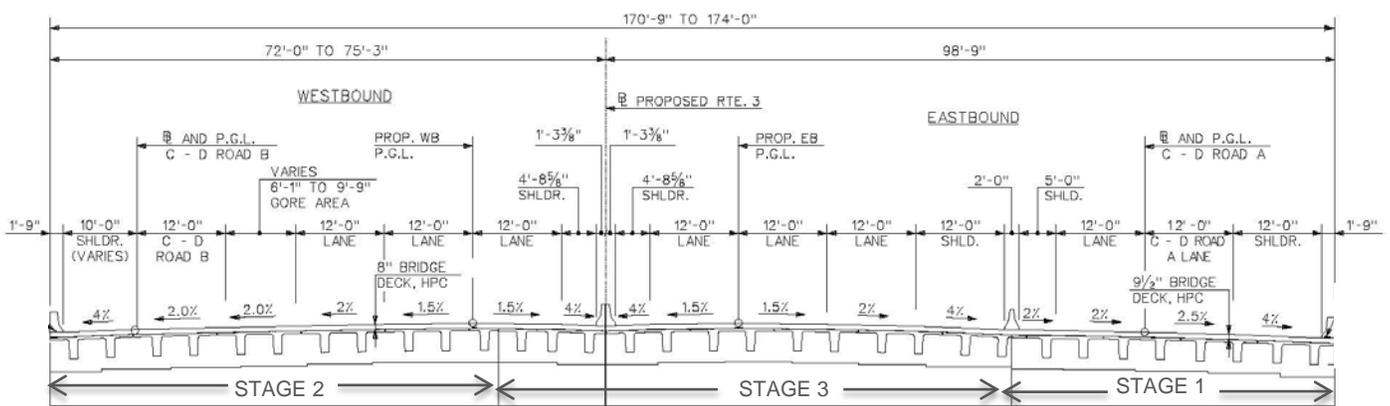


Figure 3 Bridge Cross Section³

developed to assist with the beam layout. Using the top of slab cross section, beams were laid out adjusting their flange widths and beam slopes to create a top of beam cross section that considered the minimum and maximum slab thicknesses, standardized beams

to minimize the number of different beam types for fabrication, and accounted for bridge width changes between abutments in the NEXT beam flanges. This layout procedure was completed at both abutments for each of the bridges, and was the basis for the VE design.

A spreadsheet (reference Figure 4) was developed to identify the beam bearing locations and elevations at the abutments. Challenges arose in determining the beam bearing points on the skew of the abutments while accounting for the cross section and profile of the bridge. The method chosen by the Engineer for accomplishing this was to develop the top of beam elevations at the beam flange tips and web centerlines for each of the beams along the centerline of bearings, then to project down the rotated NEXT beam section to the beam bearing locations (reference Figure 5). With these bearing locations and elevations located along the skew of the abutment the VE design team was able to update drawings to allow the construction of abutments from working points located at the form edges.

Route 3 Bridge #5						Hoyle, Tanner & Associates, Inc.			
Passaic, NJ									
WEST Abutment									
Slope of Road = -3.76% (west to east)						@ Curb @ Deck End (ft) =	67.03		
Skew of bridge = 85.704 degrees 1.496 radians						Beam Depth (in) =	36		
CL Brg to End of Deck = -1.583 ft						Bearing Thickness (in) =	1.5		
						Camber Adjustment (in) =	1.5		
						Curb Line to Edge of Deck (ft) =	1.75		
Calculated Top of Beam B1 @ CL Brgs @ Curb Line =						66.18 ft			
Calculated Top of Beam B1 @ CL Brgs @ Edge of Deck =						66.10 ft			
Beam	Web	Beam Joints	Bm Pts (in)	Beam Slope	TOB Elev	Bm Pt X - Loc	Bearing Loc. (ft)	Bot of Bm Elev	Top of Concrete Pedestal Elevations
1		1 Edge	0.000	4.000%	66.104	0.00			
	1a		37.500		66.237	37.47	3.242	63.24	63.11
	1b		97.500		66.451	97.42	8.238	63.45	63.33
		1-2	135.000		66.585	134.89			
2	2a		18.750	1.881%	66.619	153.64	12.860	63.62	63.49
	2b		78.750		66.727	213.63	17.859	63.73	63.60
		2-3	97.500		66.761	232.37			
3	3a		38.250	1.881%	66.830	270.62	22.608	63.83	63.71
	3b		98.250		66.938	330.61	27.607	63.94	63.81
		3-4	136.500		67.007	368.85			

Figure 4 Abutment Geometry Spreadsheet Excerpt

The following is a step by step process that was used to define the top of abutment information:

Step 1 – Identify the Beam 1 top of beam outer flange elevation: This point was designated as X-direction point zero (X₀) and used as the basis for establishing the X distance along the centerline of bearings across the abutment (reference Figure 5). Its elevation was established from the bridge baseline and the top of roadway cross section. The slab thickness at this location accounted for the beam camber minus dead load deflection. This ensured the minimum slab thickness would be maintained at the center of the beam.

Step 2 – Establish the beam sections: The user input the four beam points x_1 , x_2 , x_3 , and x_4 (flange tips, and web centerlines) with the distances relative to the respective beam flange location. This aided in verification of input as it easily identified the total beam width and the distance between webs should always be 60 inches. With the exception of the 2 outermost flange locations on the bridge, the input flange widths were actually $\frac{1}{4}$ " larger than actual NEXT beam pieces. This was to account for the $\frac{1}{2}$ " +/- gap between beams to allow for construction tolerance.

Step 3 – Input beam slopes: Beam slopes were input for each beam with a plus and minus direction factor for slope direction based on its relationship to point X_0 .

Step 4 – Calculate the top of beam elevation and X direction location: Equations referenced the respective beam flange point x_1 as the basis for the distance and elevation adjustments. The formulas accounted for the beam slope defined in radians relative to a horizontal plane (ϕ), bridge skew (θ), and profile (G). (NOTE: care should be taken when working with excel to identify working units for angles in degrees or radians).

X direction location for a point on a beam:

$$X_{B1-3} = X_{B1-0} + \cos(\phi_{B1}) * x_3 \quad (1)$$

Top of Beam Elevation (z) in feet:

$$z_3 = z_1 + \sin(\phi_{B1}) * x_3 / 12 - [(X_{B1-3} - X_{B1-0}) / \tan(\theta)] * G / 12 \quad (2)$$

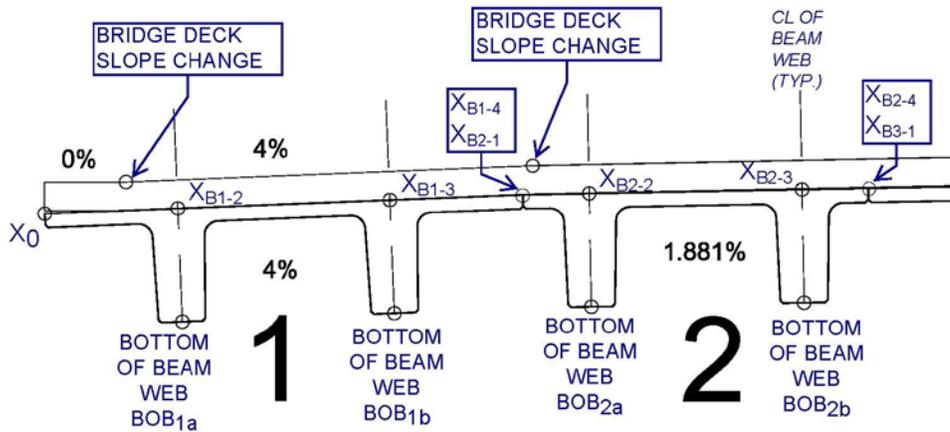


Figure 5 Cross Section at Abutment³

Step 5 – Calculate bearing locations and bottom of beam elevations: Bearing locations were defined along the centerline of bearings with respect to point X_0 (face of abutment). Adjustments for the web centerline locations and bottom of beam elevations needed to account for the beam cross slope (ϕ) and beam depth (D).

Bearing Location along CL bearings:

$$X_{B2a} = [X_{B2-2} + \sin(\phi_{B2}) * D] / 12 \quad (3)$$

Bottom of beam elevation at CL web:

$$BOB_{B2a} = TOB_{B2a} - \cos(\phi_{B2}) * D / 12 \quad (4)$$

Step 6 – Top of abutment elevations: The top of abutment elevations at bearing locations were calculated simply by subtracting the defined bearing and leveling plate thickness from the bottom of beam (BOB) elevations. This along with the precise centerline of beam bearing locations along the centerline of bearings (skewed from the bridge baseline) provided the information necessary for the Contractor to establish the abutment construction.

BEAM DESIGN REQUIREMENTS

The NEXT beams were designed using Bentley’s LEAP CONSPAN analysis software. This level of precast/prestressed bridge beam analysis software with experienced engineers using it was critical to being able to accomplish the design of the beams and completing the VE process without impacting the construction schedule. Due to the complex beam layouts required, several unique beam sizes were user created and added to the software program. Live load distribution factors were hand calculated and input into the program to accommodate the variations in beam widths and cross section differences. The beams were modeled for each of the construction stages with delineation between interior beam and exterior beam design conditions.

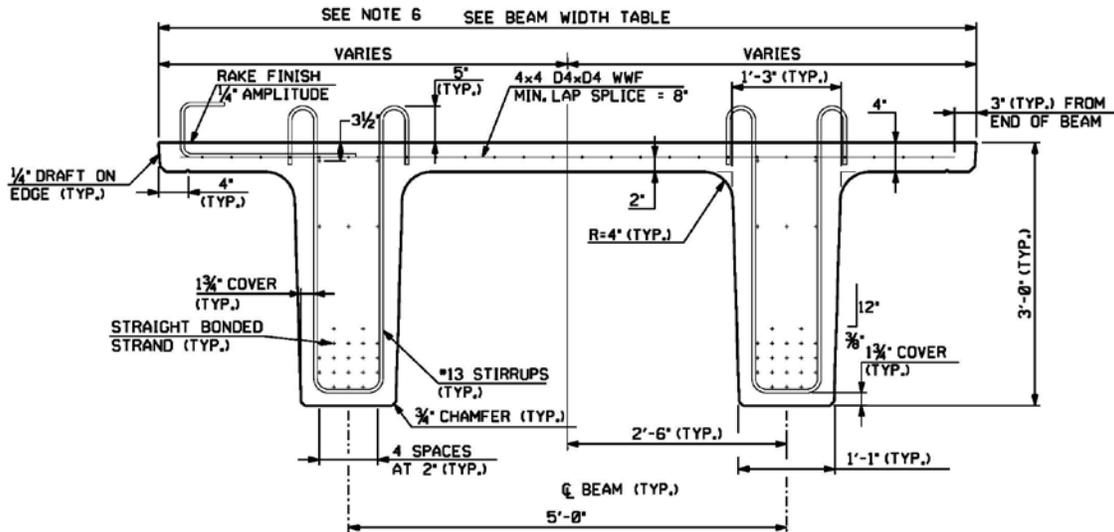


Figure 6 Typical NEXT Beam Type 36F Section³
(modified with midheight strands)

NJDOT permit vehicle: Following the first submittal of calculations for review by the Engineer of Record it was determined by the NEXT beam design team that the analysis

program was limited in its ability to model a single permit truck with a design truck in the adjacent lane (reference NJDOT 3.6.1). Under a normal project timeline this issue could be coordinated with the program manufacturer and a means of modeling this specific load case could likely be resolved. However, under the time constraints of this redesign the project team manually inserted the live load moment into the analysis program results and verified this higher applied factored moment still met the beam’s design moment capacity. Though this load condition did not change the beam design, it was a valuable identifier in the care that needs to be applied when designing with analysis programs and the level of understanding required from the user to manipulate input and output for the project specific requirements that may occur.

Tension in the bottom of beam: The NJDOT Design Manual² requires that prestressed beams be designed for Zero tension in any part of the beam at Service Limit stresses after losses (NJDOT 5.9.4.2.2). This differs from the AASHTO¹ limit of $0.19(f'c)^{0.5}$ (AASHTO Table 5.9.4.2.2-1), and resulted in a significantly higher number of strands required as displayed in the table below.

Location	NJDOT Tension Limits (Final 1, Service III)			AASHTO Tension Limits (Final 1, Service III)		
	# Strands	Allowable Tension	Actual Tension* ksi	# Strands	Allowable Tension*	Actual Tension* ksi
Bridge #3 Type 32F	36	Zero	-0.048 Top 0.073 Bottom	28	-0.537	-0.490 Top 0.089 Bottom
Bridge #5 Type 36F	50		-0.039 Top 0.015 Bottom	40		-0.385 Top 0.028 Bottom

Figure 7 Tension Limit vs. Beam Strand Comparison Table

The project team proposed to the Engineer of Record and NJDOT that this state specific requirement for zero tension be waived and to allow the VE beam design to adhere to the AASHTO guidelines. This proposal was ultimately rejected and the team continued with the beam design per NJDOT guidelines. Multiple iterations of CONSPAN analysis were run to find the strand configuration that met both the strength requirements for the structure and this Service Limit stress condition. The VE design team met the design challenges for the beams under the differing conditions from fabrication to introduction of live load by adding an upper-mid height row of strands. This row of strands assisted in distributing the prestress loads within the beam while reducing the tensile stresses in the bottom of the beam. The mid height row of strands differs from the typical strand layout as illustrated in the PCINE NEXT Beam guide⁵ which confines bars to the bottom of the beam. The Precast fabricator was well equipped to handle this adaptation to the NEXT Beams having bulkheads with a 2” strand pattern allowing them to meet project specific needs.

Intermediate Diaphragms: NJDOT Standards require intermediate diaphragms, which were included in the original project design using prestressed I-beams. Because of NEXT beams inherent stability in buckling resistance and ability transfer of lateral loads with its compact web shapes and shallow structure depth, intermediate diaphragms are typically not required with their usage as defined by PCINE⁵. The design team proposed

to the EOR and NJDOT that diaphragms not be required for this project as they are added cost with little to no benefit, introduce potential for cracking within the beams, and increase future maintenance responsibilities of the Owner. This proposal was accepted and the intermediate diaphragms were deleted from the project.

OTHER DESIGN REQUIREMENTS

Since the VE superstructure system presented many small but significant project changes, other designs beyond just the replacement beams were required to complete the Value Engineering process. Since the potential changes to these bridge elements were a reflection of the beam changes, the Contractor's engineer (in this case the Precast Engineer) was responsible for providing the analysis.

Pile Design Load: The original design aligned the beam bearing locations with the pile layout. The NEXT beam bearing locations did not align with the original beam bearing locations, and therefore it was necessary to evaluate the pile cap subject to the maximum dead and live load beam reactions (including skip load conditions) to determine if the cap was sufficient to properly distribute the loads to the pile locations. Loading conditions were also analyzed to determine the maximum pile design load for verification that it still met the factored axial compression resistance specified for the project. These conditions having been verified, calculations were submitted for EOR and NJDOT review and approval.

Integral Abutment Design: In addition to the change in the pile axial force the updated beam system changed the pile bending forces of the integral abutment system. The VE design team updated superstructure information in the foundation three dimensional



Photograph B: NEXT Beam at Integral Abutment

structural analysis model (provided by the EOR). The resulting change in bending forces was due to the decrease in superstructure depth and elevation change in which the lateral forces are applied to the integral abutment system. Calculations verified the original system design criteria was met, and were reviewed and processed by the EOR and NJDOT.

Deck Slab Overhang: Updated calculations were required for the bridge overhang since the depth of cast-in-place concrete deck was reduced. Interpretation as to the level of effective composite section between the NEXT beam flange and cast-in-place deck was discussed, and the project team concluded to provide dowel bars out the top of the beam flanges at overhang locations. These dowel bars accounted for shear transfer and protection of delamination between the flange and bridge deck. The resulting overhang section was an effective 12" thick and easily met the overhang design requirements of the TL-4 barrier loading.

Bearing Restraints/Level bearing pad: The original design of Prestressed I-Beams was a system that involves plumb beam installation; meaning the bottom of beam was level at its bearing in the transverse direction. Due to the profile of the bridge, beams were not level in the longitudinal direction. This was accounted for with a tapered sole plate on the elastomeric bearing pad.

The VE design with rotated NEXT beams did not provide a level bearing condition in the transverse direction. The cast-in-place abutments were carefully detailed to locate slope transition points that matched each beam's cross slope and bearing elevation. NJDOT Section 25.4² states, "Abutment seats may be sloped in the transverse direction to conform with the deck cross slope; however, bearing seats shall be set level in the longitudinal direction parallel to the direction of the beams. If the bearing seats are not set level in this direction, gravity loads will cause shear in the elastomer."

Coordination ensued between the Precast Engineer and the EOR regarding the need for beam bearing restraint during construction. The EOR was concerned that during the temporary construction condition, prior to the end diaphragm having cured, the NEXT beams in their transverse sloped bearing condition would be subject to construction loading that could cause the beams to bounce or slide over the steel sole plate on the bearing. The EOR and Precast Engineer never fully agreed on the potential for this lateral movement to occur as the Precast Engineer calculated the weight of the beams and steel/concrete friction to be sufficient to resist movement. But instead of challenging calculations, the two parties came together to form a compromise with the addition of steel angles bolted to the top of the abutment at one web of each beam. The angles were designed to resist transverse beam movement and post-installed so the Contractor was able to install with a snug fit relatively easily after the beams were erected.

OPPORTUNITY KNOCKS

NEXT beams offer many benefits, and can be successfully implemented into projects through value engineering. Experience, cooperation, and creative adaptability are the keys to success when melding the VE beam design into the original project slab, barrier, and substructure designs. States and Municipalities who are presented with NEXT beam value engineering can experience significant project savings, while meeting, if not improving upon, the project constraints.

THE RIGHT FIT

VE Schedule

Not every project will have the capability to allow for the VE structural design and review processes. Prior to submitting a VE proposal, Contractors and Precast Fabricators need to identify the amount of time required for the design of the beams and associated



Photograph C: Bridge #5 - Stage 1 completed

redesign of elements impacted by the beam change. It should be anticipated that abutments, piers, deck slabs, and barriers will at a minimum need to be reviewed for the updated superstructure system and these designs may require modifications. Updating these changes through a complete set of construction documents can be time consuming and will vary depending on the scale and complexity of the project.

Along with the time to complete design, the review process needs to be accounted for. The VE team should anticipate a review period by the EOR and Owner of approximately 2 to 5 weeks depending on the complexity of the project, with approximately 1 to 3 iterations of review. Review time and iterations can be reduced with direct communication between the Precast Engineer and EOR, and allowing for portions of the design to be submitted and reviewed segmentally.

If the Precast Engineer is also preparing shop drawings the level of beam understanding is increased through the VE design. Shop drawings can be completed more quickly with less risk of misinterpretation of the design, and they can be initiated while the design is being reviewed and contract plans are being updated.

Generally a VE design and review process can be completed including final approval within 3 to 8 months of notice to proceed. Less complicated bridges can be completed within the shorter time period, while complicated structure such as the project described in this paper will require the upper timeframe listed above.

Experience

A precast member being submitted as a VE item needs to include an experienced Precast Fabricator and Precast Engineer. The process of changing systems and trying to maintain components of the design such as pile layout, or roadway geometry requires an intricate understanding of the fabrication process and product design. For example, in the case of NEXT beams, the Engineer needs to apply the live load distribution factor differently than is done on other precast beam sections. As is the case with many precast members, fabricators gain a level of understanding of the precast/prestress operations for that piece. This experience should be considered by Owners prior to the concept approval of the VE item.

NEXT Beams

NEXT Beams have proven to be a cost efficient and attractive solution for bridge span lengths of 40 to 90 feet (reference Figure 8). As described in the introduction they offer many benefits during construction as well as long-term value. The Precast Engineer can offer guidance as to the correct implementation of NEXT beams as a substitute through the VE process.

The design of the NEXT beams needs to account for the nuances of the beam design and the particular governing code requirements. As discussed in this paper this can include; live load distribution, bearing restraints, permit vehicles, tensile stress requirements, and project specific flange widths/strand patterns.

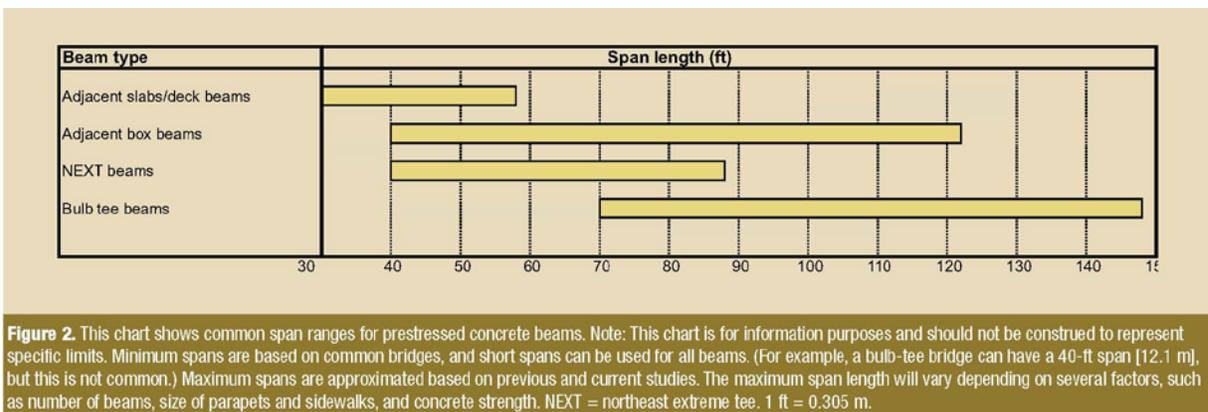


Figure 8 Beam Type Selection Chart from 2010 PCI Journal⁴

Flexibility

Implementing a new technology such as NEXT beams into a region requires a significant amount of cooperation and flexibility from the Engineer of Record and Local Authority

Particular elements of a regional code may need to be considered on how they apply to the NEXT beams and if they can be waived or modified. For this project the requirement for intermediate diaphragms was removed, but the requirement for zero tension under service loads remained. Further discussion of this code interpretation process is described in the 'Communication' section below.

In most projects the EOR releases the rights of plans and calculations to the Owner. These should be provided to the Precast Engineer to aid in the design modifications to bridge elements such as substructure, bridge deck and barriers. For the project discussed in this paper, the EOR also supplied an electronic version of their structural model for the integral abutment design. Providing this file greatly increased the speed of the substructure redesign and review process. The EOR is in a position where their design is subject to an extensive amount of changes; having an organization that understands the benefits to the Owner and is willing to cooperate, review, and represent the Owner's interests is very important to the process.

COMMUNICATION

The typical communication channels during a shop drawing process have the Precast Engineer in contact mainly with the Precast Fabricator, who in turn is in contact with the Contractor. All information typically filters through that channel.

During this VE process we concluded that the communication channels begin to flow differently; moving the Precast Engineer into a more central role. A role that is more directly in contact with the project parties as shown in the flow chart (Figure 9).

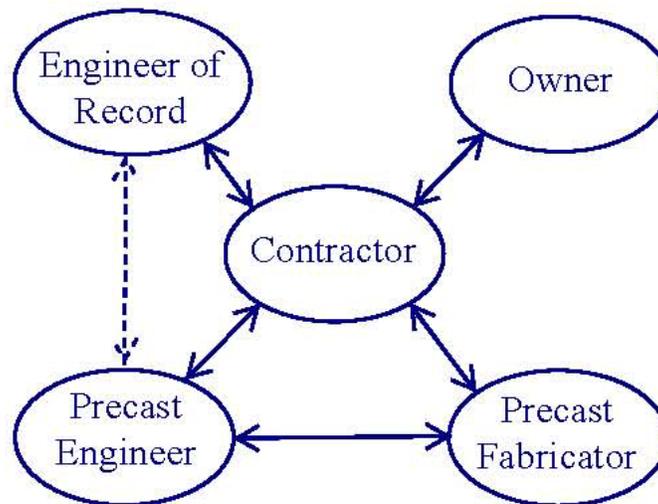


Figure 9 Communication Flow Chart

As with all projects, clear communication is a vital part of success. With direct conversations between the EOR and Precast Engineer during the calculation and drawing review process, issues were resolved more quickly and the quality and efficiency of the VE design was improved.

VALUE PAID FORWARD

NEXT beams have the proven ability to provide cost efficient solutions to Owners. The VE process may yield a minor project savings (accounting for the VE design consulting costs), but the real benefit is introducing the technology into the region so that future projects can take advantage of using NEXT beams during the Design phase of the project.



Photograph D: Stage 1 Completed Structure

CONCLUSION

When Owners are presented with NEXT beams as a VE item they can expect to see project savings with improved construction installation speed. Implementing this technology into a region through this VE process may be the fastest means of gaining design and construction experience with the system. Contractors and Fabricators should look for the opportunities to use NEXT beams and propose their use when schedule and application allows. With the right experience and communication the redesign process can be completed with high efficiency and return the many benefits that NEXT beams bring to a project.

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