Durability Assessment of Prefabricated Bridge Elements and Systems

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MD-1314--SPMSU-3-11

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STATE HIGHWAY ADMINISTRATION

Research Report

DURABILITY ASSESSMENT OF PREFABRICATED BRIDGE ELEMENTS AND SYSTEMS

MORGAN STATE UNIVERSITY
DEPARTMENT OF CIVIL ENGINEERING

PROJECT NUMBER SP309B4E
FINAL REPORT

DECEMBER 2014

Technical Report Documentation Page

Report No. MD-14-MSU-3-11	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle *Durability Assessment of Prefabricated Bridge Elements and Systems*		5. Report Date *February 2015* 6. Performing Organization Code
7. Author/s Principal Investigator: Dr. Monique Head Researchers: Steve Efe, Siafa Grose, Jerrell Drumgoole, Oladapo Lajubutu, Ryan Wright and Tyrone Hansboro, Jr.		8. Performing Organization Report No. *MSHU-Head-2*
9. Performing Organization Name and Address Morgan State University Clarence M. Mitchell, Jr., School of Engineering Department of Civil Engineering 1700 E. Cold Spring Lane Baltimore, Maryland 21251		10. Work Unit No. (TRAIS) 11. Contract or Grant No. SP309B4E
12. Sponsoring Organization Name and Address Maryland State Highway Administration Office of Policy & Research 707 North Calvert Street Baltimore MD 21202		13. Type of Report and Period Covered *Final Report 2/1/2013-2/28/2014* 14. Sponsoring Agency Code (7120) STMD - MDOT/SHA
15. Supplementary Notes		

16. Abstract

This study aims to address some of the concerns related to implementation of prefabricated bridge elements and systems (PBES) and accelerated bridge construction (ABC) in Maryland, where some barriers included assessment of the quality and durability (long-term performance). While many states are considering the use of PBES/ABC projects to shorten onsite construction time, work zone and safety factors, and user costs, the quality and durability of PBES units produced for long-term benefit is of concern to the Maryland State Highway Administration (SHA). Incomplete and noncompliant inspection processes and nonexistent waste management procedures not only affect the quality and durability of PBES units produced but can also drive costs and waste time. As such, this project focuses on the evaluation of quality assurance/quality control (QA/QC) processes during pre-production, fabrication, evaluation and transportation and storage of the PBES units. To aid in the evaluation process, work flow diagrams and decision framework were developed based on inspection checklists and incorporated into a database to guide precast plants during pre-production, fabrication, evaluation and transportation and storage phases of the PBES. The database, created in Microsoft Excel, can be used as a tool to automate the documentation process needed to ensure quality and durable products. Specific data entries such as camber measurements and crack widths/lengths are included to aid in quality processing of critical data on products, and provide a consistent means for data collection and tracking of SHA projects to help yield high quality PBES products. A link to the user-friendly, interactive database is provided within this report.

17. Key Words Prefabricated bridge elements and systems, inspection criteria, durability assessment, database, camber, crack width, crack length	18. Distribution Statement: No restrictions This document is available from the Research Division upon request.		
19. Security Classification (of this report) None	20. Security Classification (of this page) None	21. No. Of Pages 51	22. Price

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Acronyms and Abbreviations

ABC	Accelerated Bridge Construction
DOT	Department of Transportation
FHWA	Federal Highway Administration
NPP	Northeast Prestressed Products, LLC
OMT	Office of Materials Technology
PBES	Prefabricated Bridge Elements and Systems
RFID	Radio Frequency Identification
SHA	Maryland State Highway Administration

ACKNOWLEDGEMENTS

The authors would like to express gratitude to the Maryland State Highway Administration (SHA) for funding this project that has enabled students at Morgan State University to become involved in research and be exposed to practically-oriented civil engineering challenges. We are truly grateful for the support of Mr. Rodney Wynn, Team Leader of New Products and Research; Ms. Allison Hardt, Division Chief of Research; Ms. Michele Armiger, Division Chief of Concrete Technology Division; Mr. Christopher Gale, Assistant Division Chief of the Concrete Technology Field Operations; Mr. Roger Hensley, Precast Team Leader of the Concrete Technology Division; and Mr. Donald Beard, Team Leader, who provided overall project feedback and helped coordinate visits at the precast plants. A special thanks to the personnel at the Northeast Prestressed Products, LLC in Cressona, PA and Newcrete Products, Inc. in Roaring Springs, PA for being very accommodating during our site visits. The support of Dr. Z. Andrew Farkas and Ms. Anita Jones from the National Transportation Center (NTC) at Morgan State University is also appreciated. The authors would also like to extend gratitude for the support from Mr. Bruce Abernathy, Mr. David Malburg, Mr. Matthew Garbark, Ms. Sharon Hawkins, Mr. Jeff Robert, and Mr. Mark Wolcott throughout the duration of this project.

EXECUTIVE SUMMARY

This study aims to address some of the concerns related to further implementation of prefabricated bridge elements and systems (PBES) and accelerated bridge construction (ABC) in Maryland, where some barriers included assessment of the quality and durability (long-term performance), and the local construction industry's resistance to change. While Maryland and many states have already instituted more than 20 PBES/ABC projects to shorten onsite construction time, work zone and safety factors, and user costs, the quality and durability of PBES units produced for long-term benefit is of concern to the Maryland State Highway Administration (SHA). Incomplete and noncompliant inspection processes and nonexistent waste management procedures not only affect the quality and durability of PBES units produced but can also drive costs and waste time.

The focus of this research is on the development of a database, which can be used as a clearinghouse tool, to aid the automation process for documenting all inspection data, and tracking and handling of essential data from PBES products to assist in the quality assurance and quality control (QA/QC) process based on site visits to selected SHA certified precast plants. A link to the user-friendly, interactive database is provided within this report. The main objectives of this project were to:

(1) Compile Maryland State Highway Administration (SHA) inspection sheets and other checklists to develop an inspection framework for product quality control and assurance to determine the acceptability of manufactured PBES.
(2) Develop a detailed database in Microsoft Excel based on the framework developed to capture production, handling and shipping processes of PBES products.
(3) Identify practices that potentially limit production performance by critically examining process flow.

This final report synthesizes critical information on the development of quality control measures to ensure quality processes and inspection, quality monitoring requirements, and disqualification criteria of PBES for durability assessment based on observations made during three site visits to SHA certified precast plants. Observations from these visits were made during the prestressed beam production process, including material testing of the concrete that must be reconciled with inspection data sheets. Emphasis was also placed on identifying areas for quality processes and inspection during production and storage. While the precast plants seemed to meet appropriate strength requirements to release prestressed beams, other issues such as tracking beam camber, crack widths and lengths while PBES products were stored for more than one year are discussed in this report. Durability assessment of PBES products is critical since cracks can grow as a result of differential shrinkage and creep, which can lead to the potential ingress of moisture and the corrosion of top steel, and beam misalignment when time to be installed at its project site. These factors can result in strength reductions and camber-related issues the longer these beams are stored at the plant and not installed at their designated project site.

Chapter 1: Overview of Study

1.1 Problem Statement

Recent assessment of America's transportation infrastructure has still identified the need to address the current state of many existing bridges that have either deteriorated with time and/or do not meet current load ratings. The U.S. Department of Transportation (US DOT) Federal Highway Administration has focused on "accelerating innovation" through several initiatives such as the *Highways for Life*[1] program and *Every Day Counts*[2] program, which have included the use of new technologies, prefabricated bridge elements and systems (PBES) and accelerated bridge construction (ABC). While *Highways for Life* is no longer active, *Every Day Counts* is focused on identifying innovations, technology and training programs to implement innovations and new technologies for highway projects. Additional incentive programs such as State Transportation Innovation Councils (STIC) offer technical assistance and funds for state transportation agencies or other public sector STIC stakeholders to support costs for standardizing innovative practices.[3]

As of 2011, Maryland and other states such as New York, South Carolina, Illinois, Texas and Alaska have deployed more than 20 projects with PBES/ABC. Given this trend, it is anticipated that future single- or multi-span replacement bridges authorized using federal aid would have at least one major PBES that would shorten onsite construction time relative to conventional construction. While PBES/ABC offers several advantages such as shortened onsite construction time, work zone and safety factors, and user costs, the quality and durability of PBES units produced for long-term benefit is of particular concern to the Maryland State Highway Administration (SHA). Incomplete and noncompliant inspection processes and nonexistent waste management procedures not only affect the quality and durability of PBES units produced but can also drive costs and waste time. As such, there is a need to assess the durability of PBES units for their long-term benefit.

1.2 Scope of Work and Objectives

This study was conducted to evaluate critical information on the development of quality control measures to ensure quality processes and inspection; and the quality monitoring requirements based on observations made during four site visits to SHA certified plants: three (3) visits to Northeast Prestressed Products, LLC in Cressona, PA and one (1) visit to Newcrete Products in Roaring Spring, PA. From this study, data was collected and tracked on beams that were fabricated and eventually stored at the plant. Keen observations were made to ensure that proper SHA inspection regulations were followed and met. Actual field measurements of the fabricated beams were taken on two different visits to compare to the specified camber and dimensional tolerances since differences can affect the final product.

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[1] https://www.fhwa.dot.gov/hfl/
[2] https://www.fhwa.dot.gov/everydaycounts/
[3] https://www.fhwa.dot.gov/stic/

The goal of this research was to develop a database, which can be used as a clearinghouse tool for documenting all inspection data, and tracking and handling of essential data from PBES products to assist in the quality assurance and quality control process. The main objectives of this project were to:

(1) Compile SHA inspection sheets and other checklists to develop an inspection framework for product quality control and assurance to determine the acceptability of manufactured PBES.
(2) Develop a detailed database in Microsoft Excel based on the framework developed to capture production, handling and shipping, and storage processes of PBES products.
(3) Identify practices that potentially limit production performance by critically examining process flow.

1.3 Organization of Report

This report is divided into five chapters. Chapter 1 presents the problem statement, scope of work and objectives of this study followed by an outline of the report. Chapter 2 provides background information on previous studies related to PBES and quality assurance and quality control, which is documented in a literature review. Chapter 3 discusses some of the observations and data collected during the site visits that provided a basis for the database to automate the documentation process of some of the data collected. Next, Chapter 4 presents the details of the database and its contents. Lastly, Chapter 5 presents a summary of the work, recommendations, and a discussion of future work.

Chapter 2: Literature Review

2.1 Introduction

The use of prefabricated bridge elements and systems (PBES) is one means to enhance and accelerate bridge construction in the United States by reducing construction time on-site, reducing safety risks, protecting the environment, and enhancing convenience for travelers.[4] Precast concrete products used for accelerated bridge construction (ABC) are usually made-to-order for a specific project. Yet, the manufacturing process of these products is sometimes complex as human, materials and mechanical components must be managed concurrently and be quickly integrated into a production system (Ballard and Arbulu, 2004). In order to develop processes that address factors concerning durability of PBES, which is of particular interest to SHA, specific emphasis is needed to assess the quality assurance and quality control (QA/QC) methods of the PBES process during its ***four major phases***:

1) Pre-production (including lean manufacturing and overall process)
2) Fabrication (ensuring camber and dimensional tolerances)
3) Evaluation (i.e. curing process to meet concrete strength requirements especially at release, measuring crack widths, etc.), and
4) Transportation and storage (preventing major damage while handling, etc.)

The next sections discuss in more detail how these metrics can be evaluated and their importance for ensuring a quality product and minimizing waste (part of the lean manufacturing process) during these four major phases.

2.2 Implementation of PBES in the Mid-Atlantic Region

PBES has been implemented across 39 states including Maryland, and has been used on projects such as Route 7 over Route 50 in Fairfax Virginia, and on precast deck panel bridges in Florida. In 2002, the Virginia Department of Transportation (VDOT) replaced the superstructure of its Interstate 95 James River Bridge in Richmond with prefabricated superstructure segments. More than 100 superstructure spans were replaced in nighttime closures using high–capacity cranes and conventional flatbed trailers, with all lanes remaining open to traffic from 6 a.m. to 7 p.m. The superstructure replacement was completed in just 137 nights over 17 months, versus 24 to 36 months using conventional methods. Project costs came in at 11% below the engineer's estimate.

In 2004, the Washington State DOT replaced the deck of the Lewis and Clark Bridge on State Route 433 that crosses the Columbia River between Washington and Oregon during 124 nighttime closures plus three weekend closures, versus the 4 years it would have taken using conventional construction methods. This allowed the steel through–truss bridge to be kept open to traffic during rush hour, eliminating the need for a long detour. More than 100 36–foot–wide full–depth lightweight concrete deck panels, totaling 3,900 linear feet, were installed using a special frame mounted on self-propelled modular transporters (SPMTs). Every night an existing

[4] https://www.fhwa.dot.gov/everydaycounts/technology/bridges/intro.cfm

deck segment was removed and a new panel installed. Installation costs were 38% below the engineer's estimate.

Also in 2004, the New York City DOT replaced the Belt Parkway Bridge over Ocean Parkway in Brooklyn while completely reconfiguring the interchange and parkways, and did so without reducing traffic lanes during rush–hour traffic. Prefabricated components included the piles, T–walls, cap beams, superstructure, parapets, barriers, and approach slabs. Bridge assembly required only a few nights over several weeks. The entire project was constructed in 14 months, including a three–month winter shutdown, rather than the three to four years conventional construction would have required. The project came in at 8% below the engineer's estimate.

In October 2007, the Utah DOT replaced the four–span deteriorated 4500 South Bridge that crosses I–215 East near Salt Lake City with a one–span steel girder bridge in just one weekend. The old bridge was removed and the new bridge installed using SPMTs. The 4500 South Bridge was reopened to traffic in 10 days, and I–215 was detoured for just two days.

Although PBES improves the overall construction experience, there are some problems that will be encountered during the process. For instance, cracks can grow as a result of differential shrinkage and creep, and consequently, can lead to the ingress of moisture and corrode the top steel thereby reducing the strength and durability of the PBES. Research conducted by Alvi et al. (2012) has revealed that differential shrinkage and creep were responsible for longitudinal cracking at the vertical precast panel/cast-in-place interface region along the girder support. Differential shrinkage is a function of the time that elapses between the casting of the precast panel and the pouring of the cast-in-place concrete. This parameter was also monitored during the site visits associated with this study to determine its effect, if any, on the quality of the beams produced.

2.3 Quality Assurance and Quality Control of PBES

The quality of prefabricated bridge elements and systems (PBES) is dependent upon various participating constituents, some of which are not effectively controlled or sustainable. For instance, the comprehensive precision associated with production of precast steel is sometimes deficient in concrete due to the time dependent variables that dictate its strength and reliability. Acceptance of PBES is therefore dependent on its quality; high cost and low productivity are related to poor quality and affects the business future of PBES manufacturers. To achieve product precision and improve quality levels, most production plants employ novel technologies in batching and stringent quality regulatory measures. Integration to technology that could monitor and control processes aside, testing the material components of PBES products to detect changes in process or product qualities are ways to improve PBES quality. However, lowering manufacturing costs by reducing the likelihood of defects and waste and ensuring consistent improvement of processes are some of the challenges manufacturers face.

The plant production systems must ensure value-added through improvement of the supply chain and constant measurement of consistency with site requirements. Reducing activity time, cost processes and identifying bottlenecks will help production processes and improve time delivery, highway user satisfaction and supplier-client trust. These factors promote a “win-win” situation from the manufacturers, to the contractors, to the highway user. A holistic approach to PBES

QA/QC should, therefore, consider cost, materials, public needs and specification, product ergonomics (size and shape), production environment (efficiency of workflow and recycling), plant production capacity (just in time, batch, continuous or single item), technology use (modern or antique), identity (reliability of products), personnel culture (values and beliefs) and aesthetics.

All PBES production-supply chain framework should incorporate inspection criteria and value monitoring into its objectives. Implementation of a production-supply chain framework, including both inspection criteria and value monitoring, at the various stages mitigates the difficulty in remediation of product defects and the level of risk associated with product rejection as it reinforces PBES product life cycle management. The maintenance of an effective database by plant management enables product tracking for details of compliance and/or defective products. This helps create standards to improve finished products and enhance product identification or traceability from production to shipping to installation on site.

2.4 Lean Production and Process Improvement for Precast Manufacturing

Past research has focused on influential concrete characteristics, material cost, and construction practices (Aiticin et al., 1990; ACI, 2002; Hooton, 1997 and Ray et al. 2006). Product value must constantly be incorporated into the production stream otherwise PBES manufacturers could be faced with a decline in operational productivity and financial pressures. According to Womack and Jones (1996), application of lean production efforts, as metrics, can be used to measure the current manufacturing situation in plants and provide efficient ways to improve manufacturing quality, minimize inventory and waste, and ensure continuous improvement. Kotelnikov (2001) established that for most production operations, only a small fraction of the total time and effort actually adds value to the end product and for the end consumer.

Ray et al. (2006) extended the concept of lean production for process improvement to precast product manufacturing and it aimed at protecting production integrity and resources maximization. Eight types of waste were identified, resulting from mapping and classification of processes in plants and provision of verifiable tools to improve productivity. According to Ray et al. (2006), leveraging the principles of lean manufacturing could help achieve a 20% rise in profit per year through the use of these five principles:

a. minimization of cost and risk,
b. rework and scrap through re-use,
c. improved efficiency through elimination of errors in misinterpretation of design requirements,
d. ensuring standardized components through accuracy, and
e. increased plant capacity and effective communication of product information across procurement, production and the supply chain.

Lean manufacturing also facilitates fast and cost-effective implementation by accelerating production decision cycle, engagement of all employees in the continuous improvement process, and acting on opportunities for improvement, while ensuring optimal productivity throughout the product chain network. In this study, principles of lean manufacturing will be accessed to determine if additional benefits can be gained at the plant to produce better quality products, minimize waste, and improve overall efficiency at a precast plant.

2.5 Concrete Characteristics from Curing Processes

To meet demands and achieve high early strength, manufacturers of precast concrete members raise concrete temperature through steam curing, thereby aiding the cement hydration process (Badie and Tadros, 2008; Ray et al., 2006). This also improves its strength, durability performance and structural characteristics (AC1, 2002). According to Byle (1997), the use of high performance concrete (HPC) for bridge elements provide potential benefits such as longer spans, reduced maintenance, longer service life and lower cycle costs. Crack in members are mostly due to improper curing (Pruski et al., 2003). Water curing is believed to be the most effective method for structures. Ultimate strength is either the same or more than that obtained by steam curing for 28 days. Scholz and Keshari (2010) made a comparison between three different curing regimes; water curing, steam curing followed by water curing and steam curing followed by ambient curing. The cement used plays a key role in the characteristics of high performance concrete. The type used depends on the desired characteristics of the HPC and the environment it will be subjected. Masad and James (2001) and Lawler and Krauss (2005) performed studies by developing concrete mix designs using different cementitious materials quantities, where they found that achieving below five to six percent air entrainment, fly ash addition and water to cement ratio below 0.35 increased freeze-thaw durability and strength performance.

2.6 Camber and Dimensional Tolerances

Accurately achieving camber and deflection of members during production is a common challenge faced by precasters. Many DOTs have previously investigated associated issues resulting from excessive discrepancy between the specified and actual camber which can cause problems for construction. In an attempt to study the causes of changes and delays during bridge construction, Sanek (2006) investigated the camber difference between predicted and field measurements of prestressed girders. Kelly et al. (1987) and Byle (1997) carried out field instrumentation on long-span bridge beams to observe their deflection time-dependent behavior. Kelly noted that the slight variation in camber for eight identical AASHTO Type IV girders at the time of prestress transfer. Kelly et al. (1987) also investigated the effect of curing method on the camber at prestress transfer of cored slabs and box beams. For heat-cured girders, the mean relative error of the camber was 70% while the moist-cured girders suffered approximately 20% error. The camber error was more pronounced in the heat-cured girders given the thermal gradient that can occur within the concrete at transfer due to uneven cooling, reduction in the prestressing force, and thermal expansion of the strands in heat-cured precast members. As such, camber and dimensional differences between predicted and field measurements given this time-dependent behavior can present delays when onsite, which counters the advantages of accelerating construction by using PBES. Given the importance of camber and quality control measures within the curing process, camber measurements were taken to detect differences, if any between predicted and field measurements. Significant differences in camber measurements can also delay the field installation process, which counters one of the advantages of using PBES/ABC.

2.7 Summary

In summary, several processes are critical to ensuring receipt of a quality product. These processes include production processes at a precast plant, concrete curing processes and ensuring that camber and dimensional tolerances are met. Also, the inspection process plays a vital role in aiding in the quality assurance and quality control (QA/QC) process. The next Chapter documents some of the observations made during the four visits to the precast plants, as it relates to QA/QC metrics as well as lean manufacturing principles.

Chapter 3: Observations and Data Collection from Precast Plants

3.1 Overview

A total of three (3) site visits were made to the Northeast Prestressed Products, LLC in Cressona, PA, and one (1) visit to Newcrete Products, Inc. in Roaring Spring, PA to observe the pouring of beams, batching and materials certification of concrete cylinders, measurement of camber and any crack widths/lengths and storage of beams. The overall operations of the plant were observed along with assessing the amount of waste, which was minimal at Northeast Prestressed Products, LLC. Some waste was noted at both plants, and will be discussed in the subsequent sections. One site (1) visit to observe the placement of prestressed beams for replacement of Bridge No. 10065 on MD 140 over Monocacy River (FR504B51) was also conducted. Photos and videos from the visits are documented at the project website at: http://www.moniquehead.com/#!pbes/cwuw. This section highlights some of the focal points during the visit while outlining the data collected and observations made during the site visits.

3.2 Quality Assurance and Quality Control at Northeast Prestressed Products

During the first visit to Northeast Prestressed Products (NPP), LLC on March 14, 2013, a general understanding of the plant operations, from pouring of beams to understanding the inspection process, were observed. NPP is a fully-functional large-size plant producing various precast concrete products such as I-beam girders, box beams and core slabs. According to a plant inspector, the demand for precast products is seasonal with a peak in production during the summer months with a relatively constant yet substantially lower demand during the rest of the year. During the first visit, emphasis was placed on inspection of completed beams that had been stored, where hairline and larger cracks due to differential shrinkage were seen in some of the stored beams (Figure 1).

(a) (b) (c)

Figure 1: (a) MSU grad student next to S1-A1-8 beam; (b) Oblique view of S1-A1-8; (c) Cracks found in beam

General notes were taken to show how beams were stored and stacked. Two different support conditions were noticed, which have almost same height (± 0.5-in.): the concrete pedestals have a neoprene pad running along the underside of the beams while the wood had none (Figure 2). It was also observed that the neoprene pad could have been used to account for the differential height off the ground between the two supports and/or to prevent moisture ingression.

(a) (b)

Figure 2: (a) Beams stored on wood blocks and (b) concrete pedestals

During the follow-up tow-day visit from March 21-22, 2013, the following areas were screened for quality assurance and quality control (QA/QC) per SHA inspection reporting, and shown in Appendix A. During this visit, emphasis was placed on reviewing the following criteria:

- Stressing Requirements
- Detensioning
- Prestressing Steel
- Bearing
- Batching Materials for Concrete
- Placing Concrete
- Finishing of Concrete
- Inspection of Completed Members
- Defective Beams
- Pretensioning
- Forms
- Reinforcing Steel
- Concrete Mix
- Concrete Tests
- Vibration of Concrete
- Curing of Concrete
- Transportation and Storage
- Waste

3.3 Quality Assurance and Quality Control at Newcrete Products, Inc.

Newcrete Products, Inc. is the prestressed product manufacturing arm of New Enterprise, Inc., Roaring Spring, PA (Figure 3). They are involved in various products such as single and multiple girder beams and parapets manufacturing. On October 26, 2013 an inspection visit to the plant was made to verify their concrete mix process. The plant has over 30 years in the industry and sits in an enclosed space, which already has molded formworks and materials for casting. A pre-inspection meeting with the project engineers from the precast plant and SHA inspection engineers were undertaken to understand the purpose of our inspection and request for production reports to aid in our documentation process, where MDOT approved guidelines for the pre-pour are shown in Appendix B. The following aspects of production were witnessed during the inspection visits:

Figure 3: Newcrete Products personnel on site

1. Plant organization and lean manufacturing implementation at plant
2. Strand tensioning and reinforcement and strand installation
3. Concrete pour and inspection
4. Materials and waste
5. Concrete cylinder tests

3.4 Overview of Lean Manufacturing and Lean Indices

The production criteria for lean manufacturing indicate the need for continuous improvement at each plant is reflected through the assignment of lean indices. The data collected for the lean indices measurements were for the one month during the demand-season period. The operational components were identified as material, formwork fabrication, assembly of forms and molds, concrete mixing, testing and curing, assembly and finishing, and product packaging and storage. Assessment was carried out by five members of the inspection team and data were analyzed to obtain the lean indices to measure the effectiveness of the operation at Northeast Prestressed Products, LLC and Newcrete Products, Inc.

The methodology of data analysis is to derive the dependent metrics directly from the independent variables using statistical significance of variables common to the production operations studied. In other words, a single quantitative descriptive factor (leanness) was developed from the entire set of response variables (input, output, inventories) using Factor analysis while ignoring those that cannot be easily measured (Ray et al. 2006). Five beam operations including materials, production, finishing, storage and waste were examined, and a schematic process input-output model was developed for each level. Figure 4 shows the macro-level representation for the data collection.

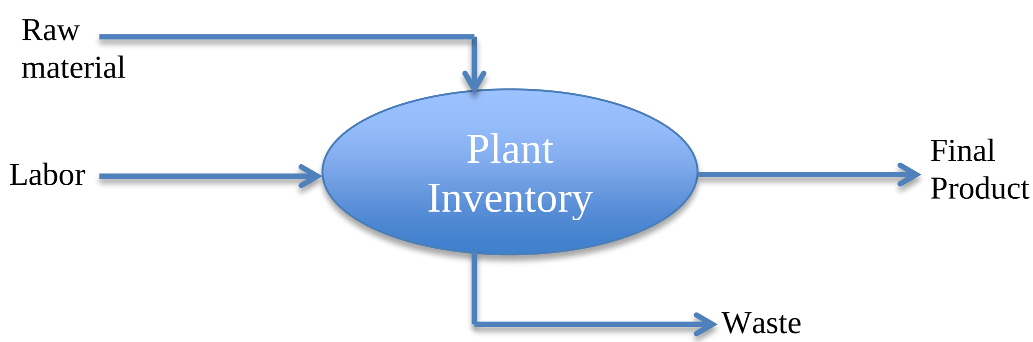

Figure 4: Representation of a macro-level model of the plant production process for data collection

The operations at each plant were then transformed to a common unit of measure "labor hours" (for example, the number of hours to make a beam). Thus, to avoid statistical bias in the model and make equivalent comparisons, all values in the variables were standardized with respect to man-hours.
For example,

$$Production = \frac{Total\ shipped\ products}{Total\ labour\ hours}$$

$$\text{Material} = \frac{Total\ \text{material cost}}{Total\ labour\ hours}$$

$$\text{Inventory} = \frac{\text{Raw material} + \text{product inventory}}{Total\ labour\ hours}$$

$$\text{By} - \text{Product} = \frac{\text{Finished Product}}{Total\ labour\ hours}$$

Also, inventory turnover was determined from ratio of the quantity of sold products to the sum of the products in the inventory

$$Product\ turnover = \frac{Total\ shipped\ product}{Final\ product\ inventory}$$

The newly formed variables were again transformed to standard scores to normalize the data (Ray et al. 2006).

$$Z = \frac{(X - \bar{X})}{s}$$

where,
Z is the fully standardized response variable
X is the original data value
$\bar{X}$ is the sample mean
s is the sample standard deviation

3.4.1 Lean Indices for Northeast Prestressed Products, LLC and Newcrete Products, Inc.

The lean indices of the individual operations were evaluated based on the following categories: 1) Waste minimization, warehouse safety / cleanliness, 2) Product turnover, 3) Dimension and tolerance, 4) Material inventory, and 5) Storage. A higher index indicates more "leanness" whereas a lower index indicates a need for improvement in that particular area as it relates to lean manufacturing. The main purpose of the lean indices is to identify critical areas at each plant for which processes can be improved to ultimately aid in “decreasing production costs, less rework, and enhanced production capacity (Ray et al., 2006).”

From the site visits at Northeast Prestressed Products (NPP), however, the production environment appeared to be dirty, unorganized, and unhealthy with random parts, materials, and tools misplaced on the floor, which resulted in the lowest lean index of 3.23 reflecting the need to improve waste management. This environmental concern, however, did not affect the seemingly perfect production process but was important to note for continuous improvement and work zone safety. Overall, the lean indices, which varied from 3.23 to 9, suggested that the priority of lean implementation, or improvement effort should be focused on finding ways to reuse materials or transport it to other warehouses for this purpose to minimize waste. It was noted that material inventory and storage are the leanest operations with lean indices of 6.78 and 8.44, respectively (shown in Table 1).

For Newcrete Products, waste and production environment seemed to have a higher lean index of 5.9 compared to the 3.23 lean index for waste minimization at NPP. This is primarily due to their association with another materials facility that recycles concrete and steel. Subsequently, their material inventory and storage are also the leanest operation with lean indices of 7.5 and 8.9, respectively (shown in Table 1).

Table 1: Lean indices for Northeast Prestressed Products and Newcrete Products, Inc.

VARIABLE	**LEAN INDEX**	
	Northeast Prestressed Products	Newcrete Products
Waste minimization	3.23	5.9
Product turnover	5.42	6.5
Dimension and tolerance	6.32	6.75
Material inventory	6.78	7.5
Storage	8.44	8.9

3.4.2 Strand Tensioning and Reinforcement and Strand Installation

During the visual inspection process, it was noted that a few of the ties for the reinforcement strands had loosened before concrete pour. This issue was noted and corrected. A technician adjusted the beam along its length to ensure accurate cover was achieved. The reinforcement bars were all epoxy-coated and well placed within the lifters.

Photos were taken to show how the strands were tensioned and to inspect the tensioning process, and can be viewed the project website at: http://www.moniquehead.com/#!pbes/cwuw. Beams were tensioned to acceptable limits with the “dead end” shown on the left and the “live end” shown on the right in Figure 5.

(a) (b)

Figure 5: (a) Tensioning of prestressing steel at the (a) “dead end” and (b) “live end” at Northeast Presstressed

3.4.3 Concrete Pour and Inspection

Pre-pour checklist procedures were implemented to ensure adherence to the PCI QC Manual requirements. These include forms, position and state of reinforcement and strands, concrete mix to specifications; slump and air test, equipment functionality, etc. (see Appendix B). At Newcrete Products, preparation for the pour was mostly dependent on knowledge from years of experience compared to Northeast Prestressed Plant (see Figure 6) with more organized patterns of operation. Nevertheless, both plants met requirements for precast product production.

According to Shanafelt and Horn (1980), the term *inspection* refers to the physical act of obtaining data on the condition of a structural element. Assessment is defined as the process of reviewing or making an interpretation of (inspection) data/ conditions, structural analysis, and other decision-making processes. *FHWA Bridge Inspectors Training Manual 90* (FHWA Manual 90) is the most common reference guide for the inspection and assessment of prestressed concrete I-beam bridges and it covers the mechanics, materials and inspection practices (Hartle et al., 1995). An excerpt from the Manual’s basic concrete inspection section:

> *When inspecting concrete structures, note all visible cracks, record their type, width, length and location. Any rust or efflorescence stains should be recorded. Concrete scaling can occur on any exposed face of the concrete surface, and its area, location, depth, and general characteristics should be recorded. Inspect concrete surfaces for delamination of hollow zones, which are areas of incipient spalling, using a hammer or a chain drug. Delamination should be carefully documented using sketches showing the location and pertinent dimensions.*
>
> *Unlike delamination, spalling is readily visible. Spalling should also be documented using sketches, noting the depth of the spalling, the presence of exposed reinforcing steel, and any deterioration or section loss that may be present on the exposed bars. There are many common defects that could occur on concrete girders: cracking, scaling, delamination, spalling chloride contamination, honeycombs, pop-outs, abrasion, reinforcing steel corrosion and deterioration.*

Also the tool for inspection, visual aid, measuring, and documentation that many states use for inspecting prestressed concrete I-beams are covered in FHWA Manual 90. Shanafelt and Horn (1980) identified tools aiding in the inspection of concrete beams, including a magnifying glass, flashlight, camera, mirrors and optical crack gauges. Cracks can be identified as hairline, medium or wide cracks. In prestressed concrete beams, all cracks are significant. According to the manual, the length, width, location, and orientation (horizontal, vertical, or diagonal) and the presence of rust stains or efflorescence or evidence of differential movement on either side of the crack must be noted. Six steps are outlined for inspecting the prestressed concrete I-beams:

1. Examine the areas near the bearings for spalling concrete
2. Check beam flange surfaces for longitudinal cracks. This may indicate deficiency of prestressing steel.
3. Inspect the tension and shear zones of the beams for structural cracks. Any crack should be carefully measured with an optical crack gauge and documented.
4. Examine underneath the beams for alignment and camber of the prestresed beams. Signs of slope deflection usually indicate loss of prestress.
5. Investigate the beams for any collision damage. This is a major cause of damage to prestressed I-beams.
6. Examine thoroughly any repairs that have been made previously. Determine if the repaired areas are functioning properly. Effective repairs and patching are usually limited to protection of exposed tendons and reinforcement.

(a)

(b)

(c)

(d)

Figure 6: (a) Formwork, (b) Concrete test, (c) Concrete Pour, and (d) Strand Inspection at NPP

3.4.4 Condition Assessment of Poured Beams

Condition assessment of the prestressed concrete I-girders' camber and crack widths (shown in Figure 7) is necessary to determine the level and appropriate repair technique or extent of suitability. The condition states for the girders describe the level of distress at the beam-end that progress with time. Crack locations, type, crack widths and crack lengths were noted (see Tables 2 and 3), utilizing the inspection data compiled during a plant investigation of sixteen (16) prestressed concrete I-beams stored at Northeast Prestressed Plant (NPP) ranging in age 3 months to 1 year.

Figure 7: Beam end cracks of prestressed concrete I-beams stored at NPP

Table 2: Prestressed Concrete Beam Crack Types Observed at NPP Site Visit

Beam ID	Crack Location and Type						
	Member End				**Span**		
	Horizontal	Diagonal	Vertical	Map	Longitudinal Flange	Diagonal	Map
S2-G1-7	χ	√	χ	χ	χ	χ	χ
S2-H1-8	χ	√	χ	χ	χ	χ	χ
S1-A1-8	χ	√	χ	χ	χ	χ	χ
S1-C1-6	χ	√	χ	χ	χ	χ	χ
S1-D1-5	χ	√	χ	χ	χ	χ	χ
S1-D1-4	χ	√	χ	χ	χ	χ	χ
S1-F1-3	χ	√	χ	χ	χ	χ	χ
S1-G1-2	χ	√	χ	χ	χ	χ	χ
S1-H1-1	χ	√	χ	χ	χ	χ	χ
S1-B1-7	χ	√	χ	χ	χ	χ	χ
S2-A1-3	χ	√	χ	χ	χ	χ	χ
S2-B1-1	χ	√	χ	χ	χ	χ	χ
S2-D1-4	χ	√	χ	χ	χ	χ	χ
S2-C1-3	χ	√	χ	χ	χ	χ	χ
S2-F1-G	χ	√	χ	χ	χ	χ	χ
S2-E1-5	χ	√	χ	χ	χ	χ	χ

Note: χ denotes absence of crack while √ denotes presence of crack

Table 3: Prestressed Concrete Beam Crack Widths and Lengths Observed at NPP Site Visit

Beam ID	Crack width (inches)	Crack Length (inches)
S2-G1-7	0.013	8.2
S2-H1-8	0.012	8
S1-A1-8	0.014	7
S1-C1-6	0.013	8.1
S1-D1-5	0.0142	6.8
S1-D1-4	0.011	7.2
S1-F1-3	0.01	7.8
S1-G1-2	0.0123	6.2
S1-H1-1	0.0125	7.7
S1-B1-7	0.012	6.2
S2-A1-3	0.013	8
S2-B1-1	0.0158	9
S2-D1-4	0.0122	9.2
S2-C1-3	0.015	8.2
S2-F1-G	0.010	8
S2-E1-5	0.012	8.2

The following photos shown in Figures 8 and 9 reveal the surface finish of the beams with some small cracks and spalls, and how the beams looked before being transported to the storage area.

(a) (b)

Figure 8: Finished prestressed beams with some (a) spalling and (b) small cracks

(a) (b)

Figure 9: Finished prestressed beams with some (a) hairline cracks and (b) spalling

3.4.5 Concrete Cylinder Tests

Figure 10: Concrete evaluation

Prior to pouring the concrete into the molds, concrete tests (ring, slump and air) were carried out to ensure the concrete met the required consistency and design (Figure 10). The concrete passed the design specifications and PCI standard. The formwork was well placed on a hard base/support, though the external surface showed rust and uncleanliness. The inside of the formwork, for which the concrete was to placed, was smooth and aligned horizontally. It was noted that Northeast Prestressed Products (NPP) had a dedicated area for concrete evaluation, which promoted organization and space for testing. This dedicated area was lacking at Newcrete Products and was reflected in the lean indices shown in Table 1.

3.5 Statistical Data Produced from Data Collected from Site Visits

3.5.1 Crack Width and Camber

A t-test analysis of data (crack width and camber) obtained was implemented to investigate the difference between the specified and measured data using SigmaPlot. The following information based on crack width was processed to conduct the first t-test:

- Test type: One-Sample t-test
- Normality Test: Passed (P = 0.643)
- Number of data: 16
- Mean of data (crack width): 0.0126
- Standard deviation of data: 0.00160
- Hypothesized population mean (crack width): 0.0130
- t = -0.937 with 15 degrees of freedom. (P = 0.363)

- 95 percent confidence interval for the population mean: 0.0118 to 0.0135
- Power of performed test with alpha = 0.050: 0.142

Figure 11 shows the normal probability plot showing the frequency of the data raw residuals. The residuals are sorted and then plotted as points around a curve representing the area of the GaussianSigmaPlot plotted on a probability axis. Plots with residuals that fall along Gaussian curve indicate that the data was taken from a normally distributed population. The X axis is a linear scale representing the residual values. The Y axis is a probability scale representing the cumulative frequency of the residuals.

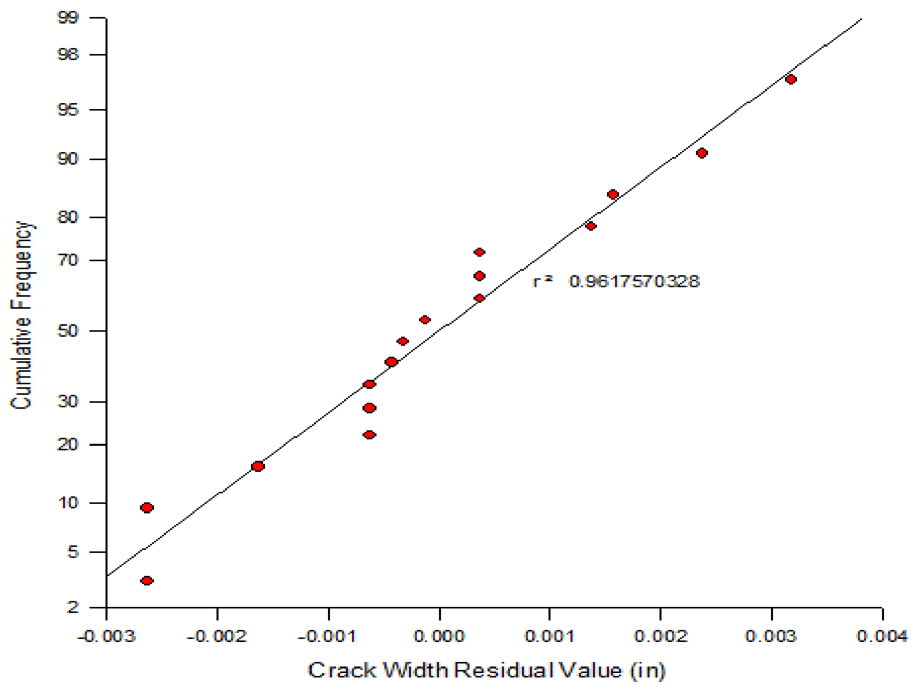

Figure 11: Normal distribution of camber width data

From the analysis, it was observed that the difference between the mean of the sampled data population and the hypothesized population mean is not great enough to reject the hypothesis that the difference is only due to random sample variability. Therefore, there is not a significant difference between the two means (P = 0.363). Also, the power of the performed test (0.142) is below the desired power of 0.800. A less than desired power indicates there is less likelihood to detect a difference when one actually exists. A plot of the crack lengths for the I-girders produced is shown in Figure 12, where beams S2-B1-1, S2-D1-4 have longer crack lengths. It is noteworthy that the cracks in all the beams are non-structural and lie within an acceptable tolerance.

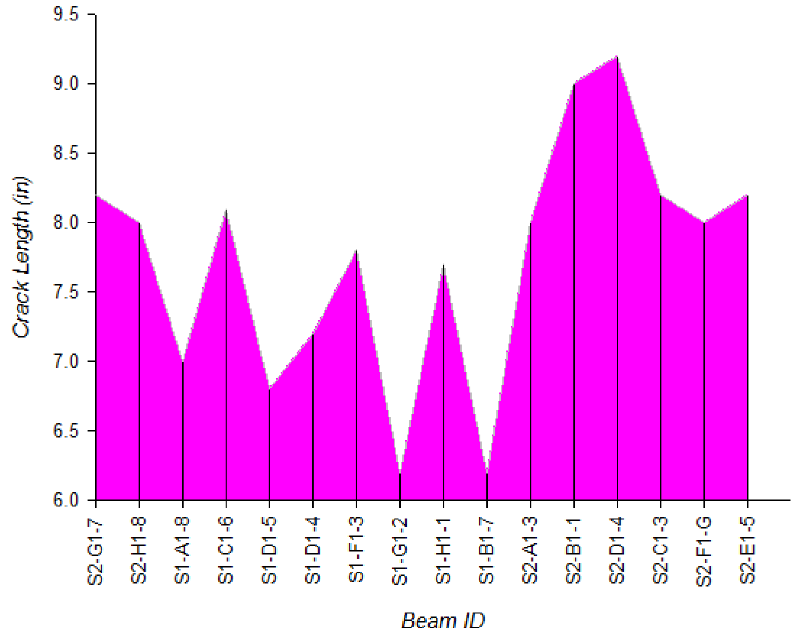

Figure 12: I- girder beams crack length plot

For beam camber, another sample t-test was conducted based on the following information:

- Test type: One-Sample t-test
- Normality Test: Passed (P = 0.643)
- Number of data: 16
- Mean of data (crack width): 2.194
- Standard deviation of data: 0.0854
- Hypothesized population mean (crack width): 2.35 inches
- t = -0.293 with 15 degrees of freedom. (P = 0.774)
- 95 percent confidence interval for the population mean: 2.148 to 2.239
- Power of performed test with alpha = 0.050: 0.059

Figure 13 shows the normal probability plot showing the frequency of the data raw residuals. The residuals are sorted and then plotted as points around a curve representing the area of the GaussianSigmaPlot plotted on a probability axis. Plots with residuals that fall along Gaussian curve indicate that the data was taken from a normally distributed population. The X axis is a linear scale representing the residual values. The Y axis is a probability scale representing the cumulative frequency of the residuals.

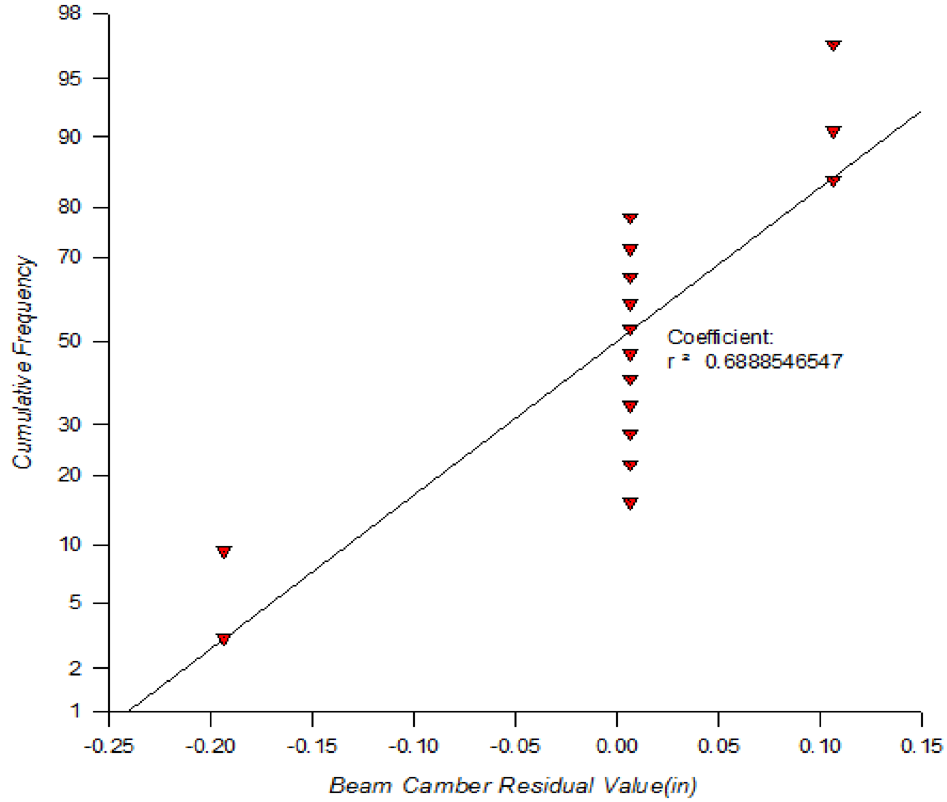

Figure 13: I-girder beams camber plot

The difference between the mean of the sampled population and the hypothesized population mean is not great enough to reject the hypothesis that the difference is only due to random sample variability. There is not a significant difference between the two means (P = 0.774). Also, the power of the performed test (0.059) is below the desired power of 0.800. This indicates there is less likelihood to detect a difference when one actually exists.

Figure 14 shows a box plot of the camber for the beam at release and on 04/17/2013, which identifies the dispersion and skewness of the camber values from the specified in the production detail drawings and represented by the green dotted line in the plot. As seen in Figure 13, there are no outliers represented on the plot, which means the camber values are not beyond normal.

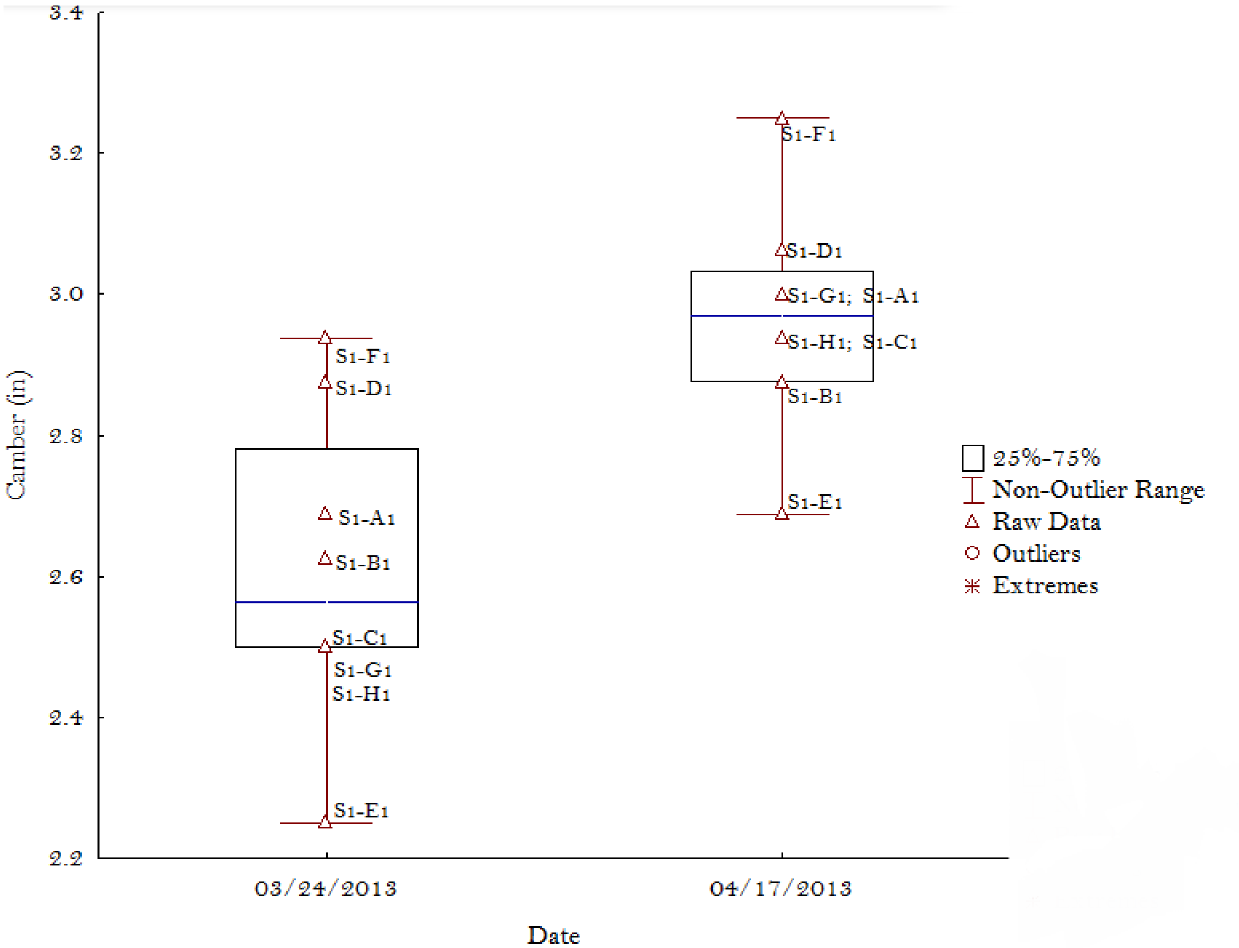

Figure 14: Box-whisker camber plot of I-girder beams

Camber measurement at release showed that majority of the beams have camber values that are below the specified value as seen in the sway of the data showing the bottom whisker higher than the top whisker. Beams S1-H1, S1-G1, S1-D1 and S1-F1 values are above the specified value of 2.35-in. while the least value was recorded for beam S1-E1. 25% of the camber values that lie below the specified value are represented by beams S1-C1, S1-G1 and S1-H1 in the plot. 75% of the camber values which lie above the specified value are represented by beams S1-B1, S1-A1, S1-D1 and S1-F1. However, the camber measurement was taken 23 days after release, and showed that beams S1-G1, S1-A1, S1-D1 and S1-F1 values were above the specified value of 3.1-in. while the least value was recorded for beam S1-E1. 25% of the camber values which lie below the specified value are represented by beams S1-B1 and S1-E1 in the plot. 75% of the camber values that lie above the specified value are represented by beams S1-D1 and S1-F1. Beams S1-H1, S1-C1, S1-G1 and S1-A1 values are within close range (±0.05in) of the specified. Majority of the beams have camber values that were below the specified value are seen in the bulk of the data, showing the bottom whisker higher than the top whisker. This implies that the beam cambers were within the expected ranges specified for their production.

3.5.2 *Concrete Strength Development*

Figure 15 shows the concrete strength of the girders tested at the precast plant. The blue and red dotted lines show the compressive strength specified on 04/16/2013 and 05/14 /2013 as 5000psi and 7,000psi respectively. The compressive strengths were above the specified minimum compressive strengths for both days. The specimens for the beams stripped on 04/16/2013 were tested on different days depending on initial testing and judgment when the minimum strength was achievable.

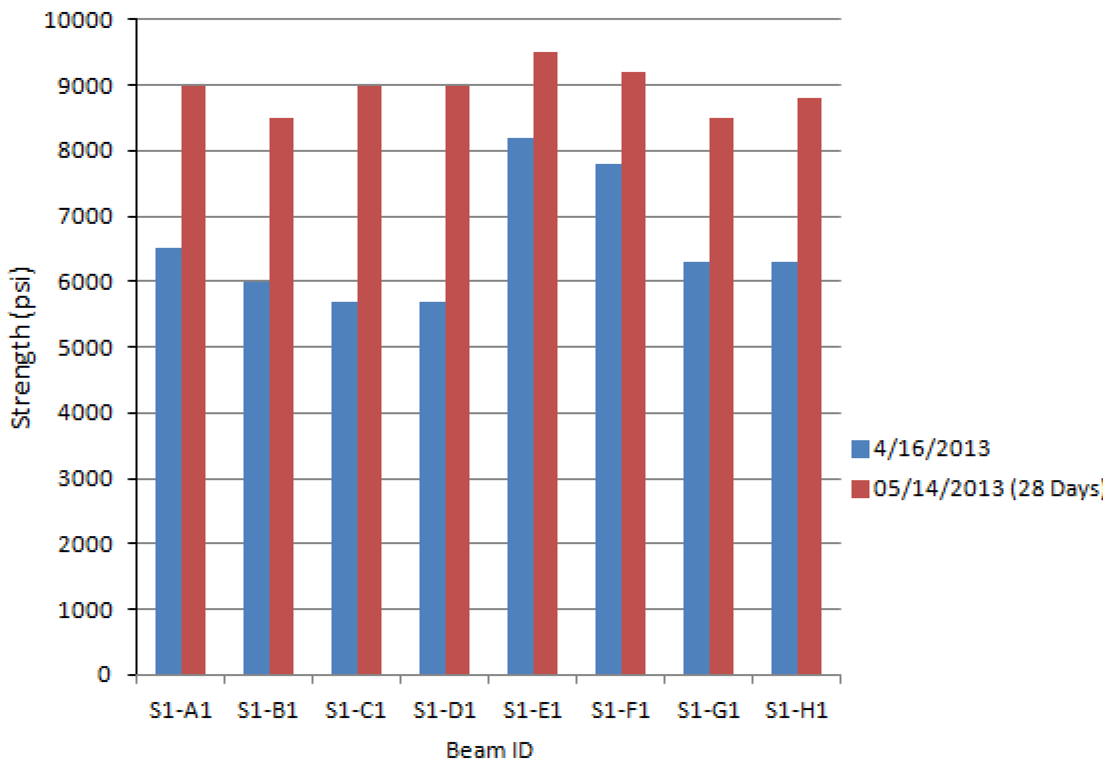

Figure 15: 28-Day Compressive Concrete Strength Development

3.6 Summary of Visits

During the visits, SHA inspection sheets and other checklists were compiled to develop the decision framework for QA/QC, which will be reflected in the database. Given the installation equipment and technology, there were no glaring "red flags" for which lack of following QA/QC procedures would inhibit the production of beams that would be disqualified. However, the following items were noted as items to address that could affect the overall quality and durability of the prestressed beams and improve QA/QC processes:

- Thin diagonal hairline cracks were found in most of the beams, notably at the ends of the beam and could have been as a result of the prestressing steel release and concrete curing process. It is believed these will not affect the structural integrity of the beams but should be noted.

- Major spalling phenomenon was not noticed in the beams except for little ingress, which has no structural implications and could be easily patched.
- Cambers are within estimated (+/- 0.2-in.) and all inspected beams have appropriate profiles according to the specifications in the fabrication drawings.
- Untidy working conditions such that lean manufacturing indices were not above a lean index of 6 was reflected in Table 1, where minimization of waste is important for promoting a safe work environment, recycling/resusing materials, and promoting quality products that can ultimately assist in minimizing costs (i.e. save money!).
- Storage/timing sequencing of beams is longer than what is specified in the initial project documents, which can affect beam camber and potentially cause alignment problems on-site that are counterproductive for PBES.

Chapter 4: Development of Database for PBES Production and Inspection

4.1 Overview of Database

A literature review, questionnaire survey and in-depth meetings with professionals were conducted to compile data on current production, storage and shipping practices and to document opinions on problems and improvement of practices. To assure bridge owners with confidence that practices are performed to standard, a quality assurance and quality control (QA/QC) inspection database was developed. To achieve this, the database is based on a framework that supports good quality data entry that is in alignment with specifications that inspectors must follow. As such, the database reflects opportunities for data entry during the production and inspection process.

A model or schema design of the inspection procedures to facilitate the realistic database development was made. Figure 15 shows the entities and relationships, logical and physical models for the database. The data collected during the field investigation are organized in Microsoft Office database. The first table of the hierarchy is the beam inventory table. This table contains the inventory information on the 16 I-girder beams that were inspected. The fields in in Figure 16 are Beam ID, County, Date of Cast, Materials Supply, Concrete Mix Summary, Member Geometry, Field Test Result of Plastic Concrete, 28-day Concrete Compressive Strength and Strand Tensioning, Feature Intersected, Deck Notes, Barrier Notes, Pier Notes, and Abutment Notes. The inspection procedures generated from the schema where used to formulate the inspection input forms, which consists of the beam general information (one-to-one relationship with the beam inventory table), Pre-pour checklist, Lean Process Evaluation, Concrete Mixing, Tensioning Finishes, Transportation to Storage, Handling and Storage at Plant and Camber Measurement. The Beam ID field is an auto-numbering column used to create relationship to other tables.

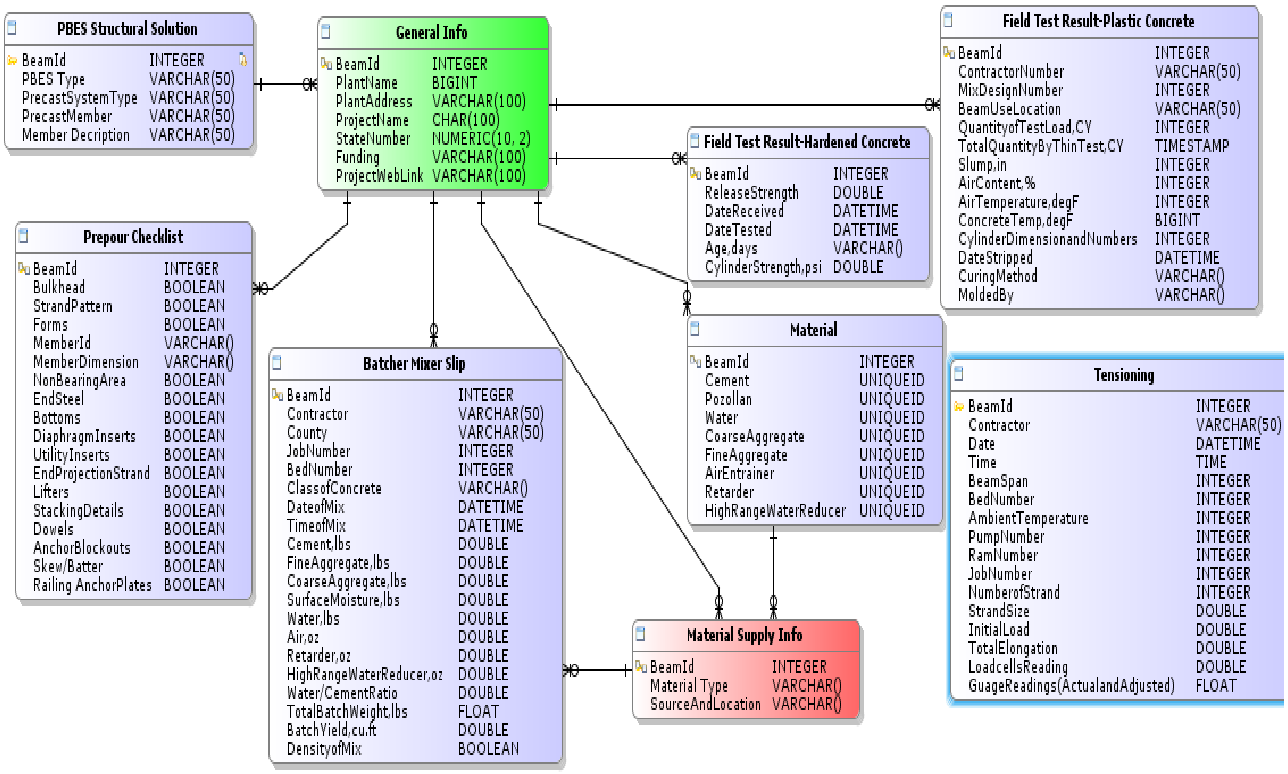

Figure 16: Database Schema for Beam Production and Inspection Process Supported by PBES Database

4.2 Flowchart and Design Process of the Database

Identifying process improvement and methods to address quality control at the precast plants and in the field will help SHA meet its business plan performance measures. This can lead to the development of quality control practices based on the durability assessment described in this report for Maryland as well as other states. The flowchart and overall design process for how the database documents various information, is shown in Figure 17 below.

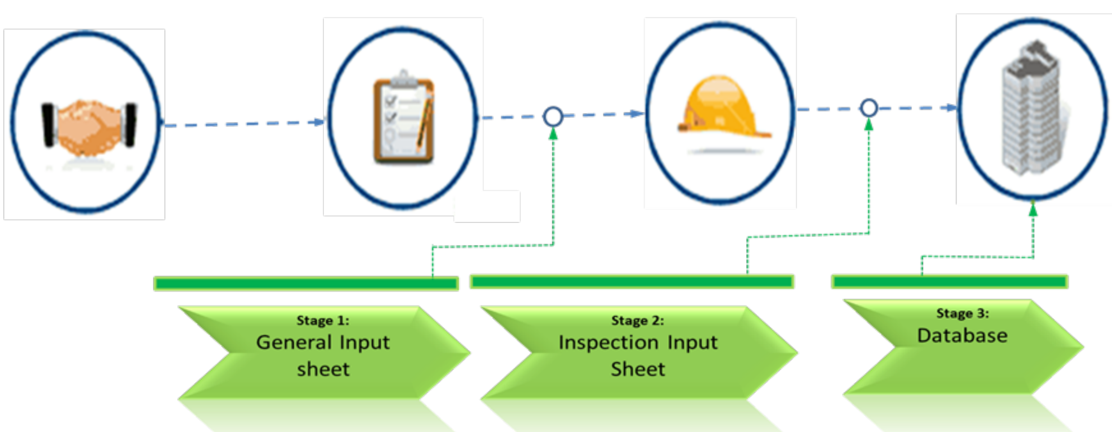

Figure 17: General flowchart and design process of database

4.3 Decision Framework for Database

The decision framework for the database is categorized into the four phases as reflected in the site visits:

- Pre-production
- Fabrication
- Evaluation
- Transportation and storage

The decision framework also points to direct references to ensure QA/QC for each step, and serves as a central clearinghouse of information to organize the work flow in each phase. As such, the decision framework used to develop the database assists users with clear identification of various criteria that matches each step. Moreover, this aids in the documentation process by having all documents, steps and checklists in a centralized location. The decision framework is shown in Appendix C, showing details for all four phases. A link to the database can be found at: http://www.moniquehead.com/#!pbes/cwuw.

Within the database, various plots have been programmed to be automatically generated for post-processing data for crack width, crack length, camber measurements and concrete strength development, thereby allowing decision-makers to assess the PBES product to ensure quality and durability potential. This also allows the end-user to compare measured values to determine if those values meet minimum standards.

Chapter 5: Summary, Recommendations and Future Work

This study addressed some of the concerns related to implementation of prefabricated bridge elements and systems (PBES) and accelerated bridge construction (ABC) in Maryland with emphasis on waste minimization at the precast plants as determined by lean indices as well as beam quality as reflected by actual camber measurements and crack lengths/widths observed while the beams were stored at the precast plants. Overall, the two (2) precast plants visited had acceptable production procedures in spite of some untidy areas and dedicated testing space for concrete evaluation. Suggestions for waste minimization practices were recommended such as transporting unused steel and concrete to materials facilities that can recycle or melt down the materials as part of the lean manufacturing process. Furthermore, to assist with durability assessment of PBES products, keeping camber measurements and crack openings within acceptable tolerances is critical since cracks can grow as a result of differential shrinkage and creep, which can lead to the potential ingress of moisture and the corrosion of top steel, and beam misalignment when installed at its project site. These factors can result in strength reductions and camber-related issues the longer these beams are stored at the plant and not installed at their designated project site.

However, two major concerns were noted: 1) lack of automated inspection processes to aid in streamlining paperwork and data management, and 2) time-sequencing of stored beams such that camber and crack measurement disparities do not become an issue once transported to the job site. To address the first issue, a user-friendly database was developed for inspectors to aid in this process as a part of streamlining data while maintaining alignment with the multiple inspection checklists and guides for the precast plants during pre-production, fabrication, evaluation and transportation and storage phases of the PBES. A link to the user-friendly, interactive database was provided within this report, and can be downloaded at http://www.moniquehead.com/#!pbes/cwuw. Moreover, data management from the electronic database can also aid in the second issue of time-sequencing/tracking of the stored beams since the information is collected and stored in a central repository/database.

As such, future work can consist of using Radio Frequency Identification (RFID) (see MD-14-SP209B4G Final Report: *Utilizing Auto ID Tracking System to Compile OFS Data*) based on the beams that can be traced/associated with the database developed within this study to allow for access of information to ensure that there is inventory control (i.e. management of large datasets or "big data") as well as accurate monitoring of beams to minimize camber and crack disparities. This will assist in minimizing costs and time that may be necessary to correct camber-related issues and large cracks when installing beams on a job site since timing of beam placement is not always known until demanded. Having such an automated system of collected data can also aid future bridge inspection and maintenance programs such that in-situ measurements can be compared to beam production (initial) data for durability assessment of cracks and camber-related measurements, which also has the potential to save MD SHA money and time.

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Appendices

Appendix A: Inspection Criteria Template Used for Beam Production

Stressing Requirements
• That the stress induced in the prestressing steel is measured both by gauges, and by elongation of the tendons and/or load cells as specified in Publication 408.
• That approved certified pressure gauges, load cells, dynamometers or gauging devices are used and re-calibrated at least once a year. Discrepancies between measured elongations and gauging measurements in excess of specifications should be carefully checked and the source of error determined and corrected before proceeding further.
• That copies of reports are reviewed for each manufacturing operation recorded by • the fabricator's Quality Control representative
Pretensioning
• Checks the casting beds and pallets periodically for deviation from a plane surface.
• Verifies the initial tensioning force
• Verifies the proper marking of reference points prior to and after the initial tensioning forces have been applied to the strands, i.e., tape on strands and paint marks.
• Notes changes in the ambient temperature and verifies that the proper adjustment is made to elongation for fixed abutment beds.
• Checks for slippage of strand anchorages
• Checks the actual dimensions of the bed layout and locations of hold-up and hold-down points to see if they agree with the dimensions shown on the approved shop drawings within the allowable tolerances. Approved hold-up and hold-down devices as shown on the shop drawings are attached in such a manner as to maintain the specified center-to-center spacing of strands in both the vertical and the horizontal directions.
• Checks for size and location of mild steel reinforcement and that minimum concrete cover is obtained including hold-down devices remaining in the beams.
Detensioning
• Forms, over yokes, hold-down, etc., which may restrict either horizontal or vertical movement of Prestressed members are stripped, or at least loosened, prior to de-tensioning. De-tensioning immediately follows the curing period required by the specifications and when test cylinders indicate the required strength is obtained. During de-tensioning operations the prestressing forces are kept symmetrical about the vertical axis of the member and applied in such a manner as to prevent any sudden (shock) loading.
• All strands are released simultaneously by hydraulic jacking. The total force is taken from the header by the jack, and then gradually released. With this method, some sliding of the members on the beds is inevitable
• The strands are released by heating and gradually cutting the strands in accordance with the posted pattern. Cutting is performed simultaneously at both ends of adjacent members. De-tensioning patterns are approved by the fabricator's Engineer.
Forms
• That unless otherwise specified, only steel forms and steel or concrete bottom forms are used for standard members. Voids for beams are polystyrene.
• The forms, bulkhead, spacers, spreader bars, and other equipment having a bearing upon the accuracy of dimensions of the completed beams. The inspector informs the producers of any discrepancies observed and overviews the necessary corrections.
• The alignment of forms before and during the casting operation. Joints between soffit, side forms and bulkheads are tight and leak proof. Plugging of holes and slots in the forms is neatly done so that the finished member has a favorable appearance.
• The void forms are anchored firmly and securely braced in their final position. The thickness of the bottom layer of concrete shall be checked before placing the voids
• Any strand or reinforcement found contaminated with a bond breaking substance is properly cleaned prior to placing concrete.
Prestressing Steel
• Prestressing steel is domestic and free of deleterious materials such as grease, oil, was, rock, clay, dirt, paint and loose rust. Strands which exhibit rust that cannot be removed by wiping with a dry cloth are not used Prestressing tendons or strands having kinks, bends, nicks or other defects are not used. • Tensioned strand are not subjected to excessive temperatures produced by torches, welding equipment or sparks. • Strands are positioned as shown on the shop drawings.
• Ducts or voids provided in the concrete for longitudinal post-tensioning tendons are formed by means of flexible PVC or metal conduit, metal tubing or other approved means or void forms are completely sealed against leakage of mortar and properly anchored in position. Lateral post tensioning tubes shall be non-flexible PVC material or other material if

approved by the Engineer.

• No more than one approved splice per strand is used
  • Multiple strand tensioning has all of the strands spliced or no more than 10% of them. If all of the strands are spliced, the average splice slippage should be considered in computing the elongation. If 10% or less are spliced, no slippage allowance is required.
  • Splices are not located within the concrete members.

Reinforcing Steel
• Steel reinforcement is domestic and the designated size and grade is according to the shop drawings and properly positioned in the members.
• Reinforcement is adequately secured
• Reinforcement bars are prefabricated into cages by welding or tying. Undercutting is not present. Reinforcing bars shall not be welded without an approved procedure.
Bearing
• The bearing areas on members are true and flat.
• Beam daps meet the dimensional requirements and tolerances
Concrete Mix
• The fabricator's mix designs are approved
• Aggregates are stockpiled and moistures controlled to keep the material above SSD.
• Cement conforms to Publication 408, section 701
• Water conforms to Publication 408, Section 720.1
• Admixtures conform to Publication 408, Section 711.3
• Calcium chloride is not used.
Batching Materials For Concrete
• The inspector assures that aggregates, cement, pozzolans, water and chemical admixtures are proportioned in accordance with the concrete mix design.
Concrete Tests
• General tests, i.e., slump, air and temperature are conducted on the same batch of concrete, independently from the plant's quality control tests. The inspector performs 10% air and slump testing, and molds two 28-day cylinders per test based on the frequency of testing conducted by the plant, or one test per week at a minimum. Four inspection cylinders per test will be molded at prestressed facilities.
• Compression tests of molded cylinders are used to determine the time of detensioning in addition to the 28-day concrete strengths.
• Samples are carefully selected and are representative of all the concrete placed in the beam. Samples are taken approximately from the middle third of the batch or from a chute which is under full flow of concrete.
• Cylinders are made, marked and handled in accordance with the approved Quality Control plan and Pennsylvania Test Method 631.
• Cylinders are marked in accordance with PTM 631 and the approved Quality Control plan and stored adjacent to the casting bed during accelerated curing and then follow the product for the full curing and storage cycles.
• The compressive strength of the concrete at stress transfer is determined by testing cylinders cured with the concrete members. Cylinder molds are required to be steel to prevent deformation during accelerated curing.
• Cylinder molds are stripped at the same time as member forms are stripped.
• Slump and air content tests are made in accordance with the Quality Control plan. Slump flow and J-ring tests are performed whenever Self Consolidated Concrete (SCC) is used. Stability of the mixture is visually assessed. Mixtures having a visual stability index greater than 1.0 are rejected.
• Test results are entered in EQMS
Placing Concrete
• Concrete is deposited as nearly as possible in its final position, except when SCC is used. Concrete that has reached initial set is not to be re-vibrated.
• Maintain the concrete temperature within 50F to 90F at the time of placing
Vibration Of Concrete
• Concrete in members is compacted by the use of external and/or internal mechanical vibrators. SCC mixtures which were not qualified for vibration during the trial batching and evaluation phase may not be vibrated.
• Vibration is not prolonged until it caused segregation of the materials.
• Sufficient vibrators to complete the compaction are used.
• Vibration is performed at the point of deposit and in the area of freshly deposited concrete. The internal vibrators are moved about in the freshly deposited concrete and across the junctions between succeeding batches of concrete so that the entire mass will be thoroughly and uniformly compacted. Internal vibrators are not pushed rapidly but allowed to work themselves into the concrete mass and withdrawn slowly to avoid the formation of air voids. Cold joints in the concrete are not accepted. If delays are

encountered, concrete which has set so long that it will not receive a vibrator easily is to be completely removed from the form, if possible, or the member rejected.
Finishing of Concrete
• After the concrete has been placed and before initial set, the beam is finished with a stiff wire bristle broom flat tine wire broom or template in a transverse direction to produce not less than 4 scores per inch, to achieve a final texture from 1/16 inch to 3/16 inch in depth. Verifies that when manual techniques are used, concrete is not penetrated to depths where the brooming or tining operation pulls coarse aggregate to the surface.
Curing of Concrete
• Special attention is given to the proper curing of all fresh concrete. Concrete is protected so that moisture is not lost during the early stage of hydration.
• The curing procedure is established and carefully controlled. Concrete is kept continuously moist until the conclusion of the specified curing period.
• After placing and vibrating, the concrete is required to attain initial set before steam is applied so that the concrete has sufficient strength to resist cracking due to thermal expansion. The length of the delay period between the finishing of the concrete and the application of the steam varies according to the mix design.
• Steam curing is completed under a suitable enclosure to contain the live steam and minimize moisture and heat losses.
• Recording thermometers showing the time-temperature relationship throughout the entire curing period are located at a spacing not to exceed 100' of the bed. The ambient temperature is verified with hand thermometers. Temperature recording charts are retained as a part of the permanent records
Inspection of Completed Members
• Members are fabricated within specified tolerances. Post-pour dimensional checks by the inspector must be performed on a minimum of 25% of completed members. When dimensional deviations exceeding the allowable tolerances • are found, 100% of the competed members produced for that structure must be inspected.
• "Bug-holes" are not excessive in number and/or size.
• Department approval is obtained before repairing any members not covered by the procedures listed in the appendix of this document.
• The depressions left in the bottom of pretensioned members with draped strands after removal of the hold-down devices are cleaned of oil or grease and the depressions are completely filled with an approved mortar or Bulletin 15 repair material in the plant, prior to storage.
• Patching is performed in accordance with approved procedures. Affected concrete is removed down to sound concrete and the patch is well bonded. • Patching is done prior to storage. Mortar repairs are moist cured. Bulletin 15 repair materials are cured according to the manufacturer's recommendations.
Transportation and Storage
• Prestressed concrete beams are transported in an upright position in accordance with specifications.
• Storage areas are flat and firm, and beams are not twisted.
• Prior to storage, beams are given a complete inspection for tolerances, camber, cracks, bearing area, stirrup placement, alignment, recessed strand areas are patched, open drains, patched vents, etc. Verification of camber must be performed not more than two weeks prior to shipment
• Necessary corrections are made prior to inspector approval for partial payment or shipment.
• The inspector's stamp of approval is placed on each accepted beam. Indelible ink is used for stamping
• Rejected members are properly identified
Defective Beams
• If the product does not meet the specifications, the beams are placed in an unacceptable status, and a Quality Report is issued to the fabricator.
• Reports are promptly issued for any damaged or defective beam to both the SME and their supervisor. There are a number of reasons that a beam to be declared defective, including:
• Cracks which exceed allowable types and limits (Refer to the "Acceptance and Repair Procedures for Prestressed Beams with Cracks" in the Appendix)
• Dimensional deviations beyond accepted tolerances.
• Damage beyond preapproved limitations.
• Other specification non-conformances.
Waste
Method of waste disposal (Any recycling)

Appendix B: 2013 Portland Cement Concrete Pre-Pour Guide for all MDOT Approved Pre-stress Plants

Maryland State Highway Administration
Concrete Technology Division

SUBJECT: Portland Cement Concrete: Pre-placement Conference

General: Coordination between all SHA entities and the Concrete Producer is essential to produce satisfactory results meeting specifications.

Purpose: To ensure that the producer is aware of all Specifications, Special Provisions and Special Projects conditions relative to placement of concrete for the referenced project.
Procedure: Prior to placing concrete for project, the Producer's Quality Control Manager shall schedule a pre-placement conference as follows:

Attendees: The Quality Control Manager shall notify the following representatives of the Date, Time and Location of the Pre-Placement conference five, (5), days in advance of the conference.

Assistant Division Chief, Concrete Division, SHA OMT
Precast Team Leader, SHA OMT
Prestressed/Pipe Engineer, SHA OMT
Producers Plant Manger
Producers QC Manager
Producers QC Inspector assigned to the Project
SHA OOS Project Team Leader
Office of Construction Project Engineer
All 3rd party representatives

Note: It is the producers responsibly to coordinate the pre-placement conference. It is SHA's responsibility to conduct the Pre-Placement Conference.

Pre-Placement Conference Record:

A record of the Pre-Placement Conference shall be prepared by the Precast Team Leader. This Record shall consist of a Summary of items discussed and a list of those in attendance, which shall be entered into the Project records, in addition they shall be distributed to the Division Chief of OMT, and all those in attendance at the conference. The record may be electronically recorded at SHA's option.

Topics for Discussion:

Topics to be discussed shall include but not be limited to the following:

A. Status of Mix Design Approval
B. Approved Plant Status
C. Have Drawings been approved
D. Are all items on Qualified Products List
E. Temperature Requirements
F. Condition of Producers Equipment and Backup Equipment
G. Concrete Testing
H. Who has Authority to reject concrete and for what reasons?

I.
    a. Slump/Flow
    b. Air Content
    c. Time
    d. Temperature
    e. Water / cement ratio
    f. Gradations (frequency guide)
    g. Moistures (frequency guide)

J. What Procedure should be followed for failing slump
K. What Procedure should be followed for failing air
L. Brand and Type of Admixture, must be pre-approved
M. Have adequate provisions been made for curing
N. Care of cylinders and number of cylinders required
O. Anticipated start date of work
    a. Request for inspection
    b. Direct inspection facilities

P. Discuss procedure following beam fabrication
    a. Required stripping strength
    b. Curing methods
    c. Camber measurements

Q. Proper storage in yard
R. Shipping notification
S. Reasons for rejection of product
    a. Repair procedure
        i. Improper stripping
        ii. Unsatisfactory molding
        iii. Honeycombing
        iv. Cracks in product
        v. Unusable lift inserts
        vi. Exposed reinforcing steel

Appendix C: Decision Framework for PBES Database