University at Buffalo Institute of Bridge Engineering

DURABILITY ASSESSMENT OF PREFABRICATED BRIDGE ELEMENTS AND SYSTEMS (PBES)

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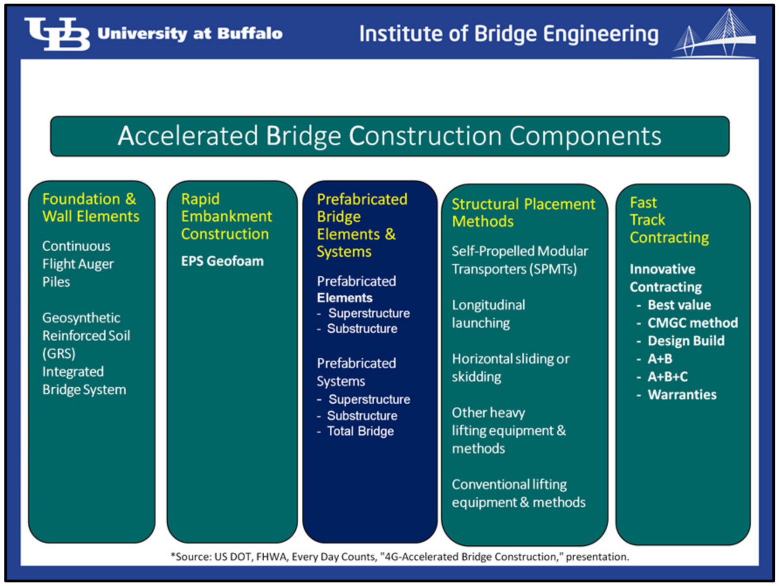
A webinar hosted by the Institute of Bridge Engineering
December 1, 2015 Buffalo NY

MORGAN STATE UNIVERSITY
THE CLARENCE M. MITCHELL, JR. SCHOOL OF ENGINEERING



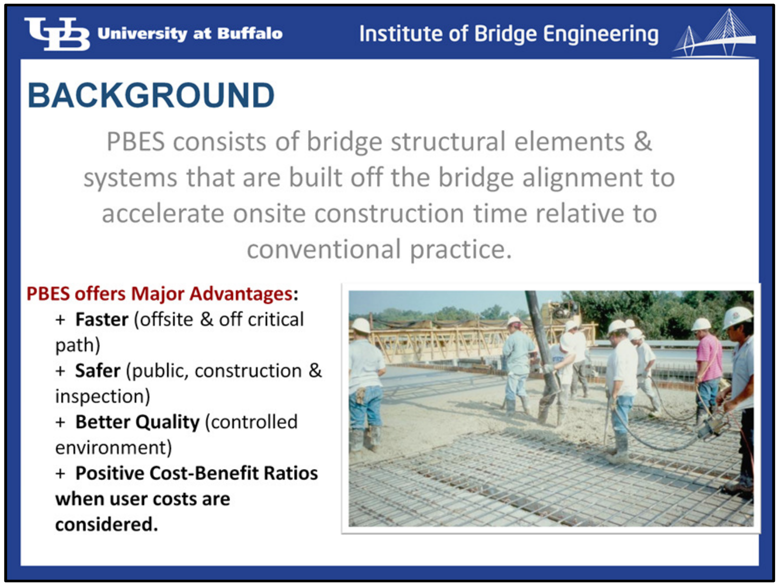
EDC PBES Vision:
To facilitate the deployment of Accelerated Bridge Construction technologies such as PBES as a standard practice for all highway projects.

EDC PBES Mission:
Advance the implementation of Accelerated Bridge Construction technologies such as PBES.

The focus is on:
- *speeding construction time,*
- *minimizing traffic impacts,*
- *improving durability,*
- *increasing safety,*
- *and reducing environmental impacts during highway construction projects throughout the transportation community.*

ABC employs structural & geotechnical engineering technologies to help agencies & the traveling public save time and money when bridge rehabilitation or reconstruction projects are being implemented.

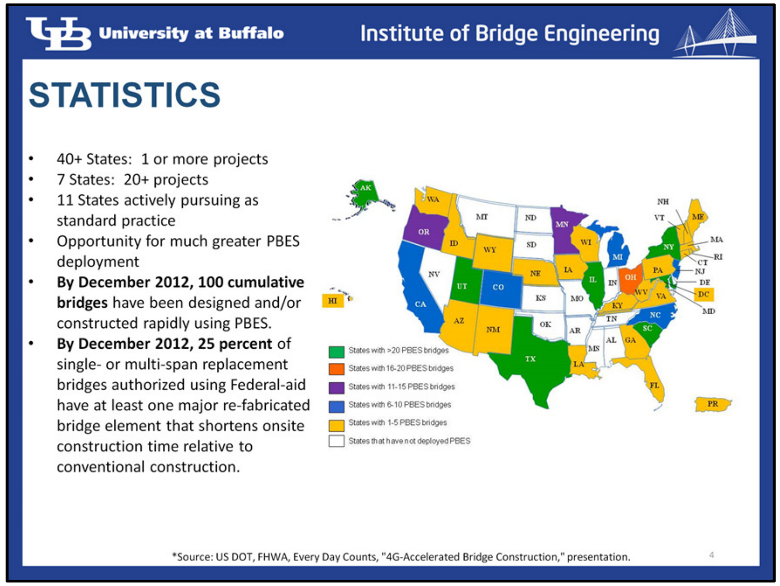
These are the major components of Accelerated Bridge Construction.
Deploying any one component will save money and time.
Implementation of PBES contributes to the success of ABC, and it is an important element to consider when planning a project.



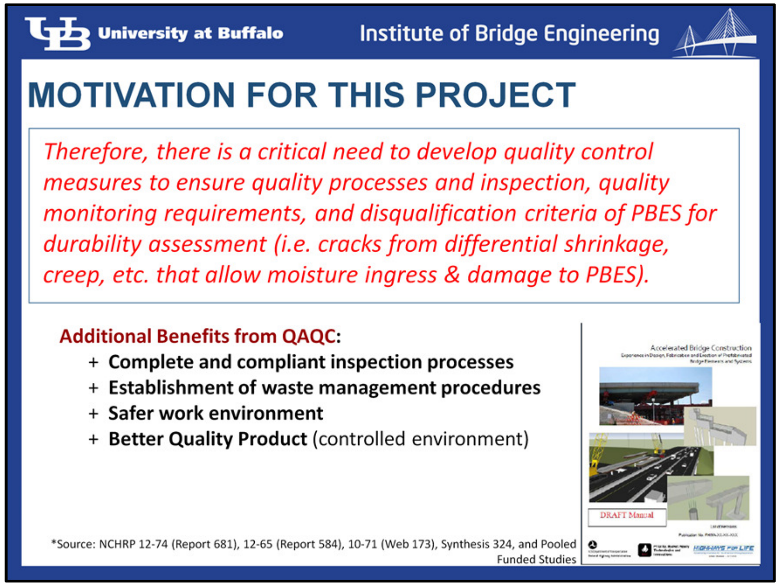
Why Accelerated Bridge Construction?

Prefabricated bridges offer significant advantages over onsite cast-in-place construction.

Among these advantages are:
- a substantial reduction in onsite construction time-
- reduction in traffic and environmental impact,
- lower costs resulting from offsite manufacturing and standardized components and positive cost-benefit ratios when user costs are considered.
- improved safety due to reduced exposure time in the work zone. The controlled environment of offsite fabrication also ensure quality components for good long-term performance.



By December 2012, to accelerate bridge construction, 100 cumulative bridges have been designed and/or constructed rapidly using PBES.



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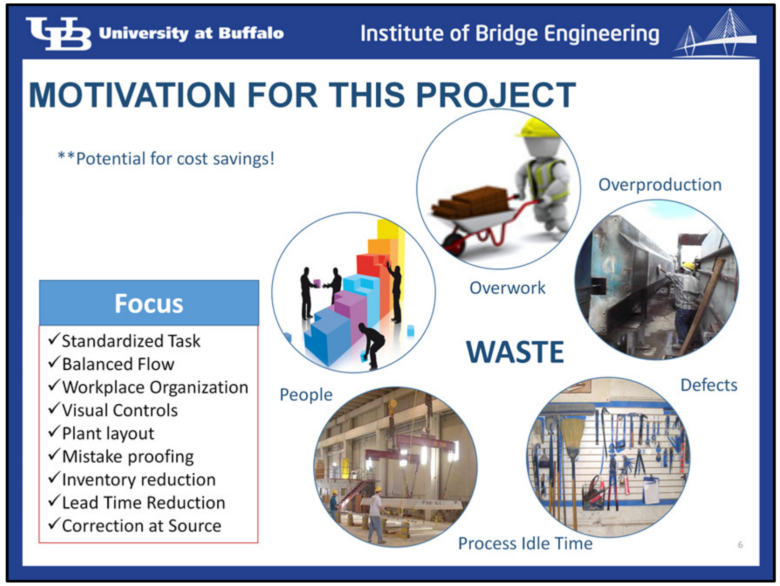
Given this demand, there is a need…



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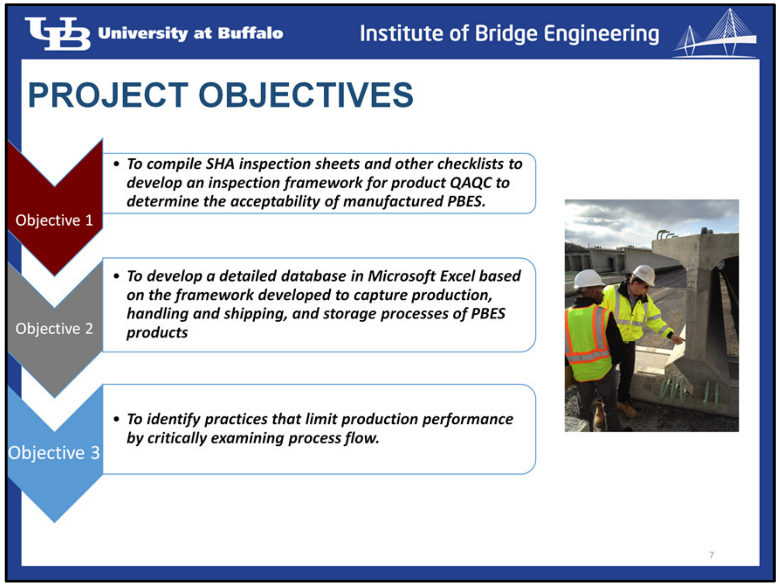

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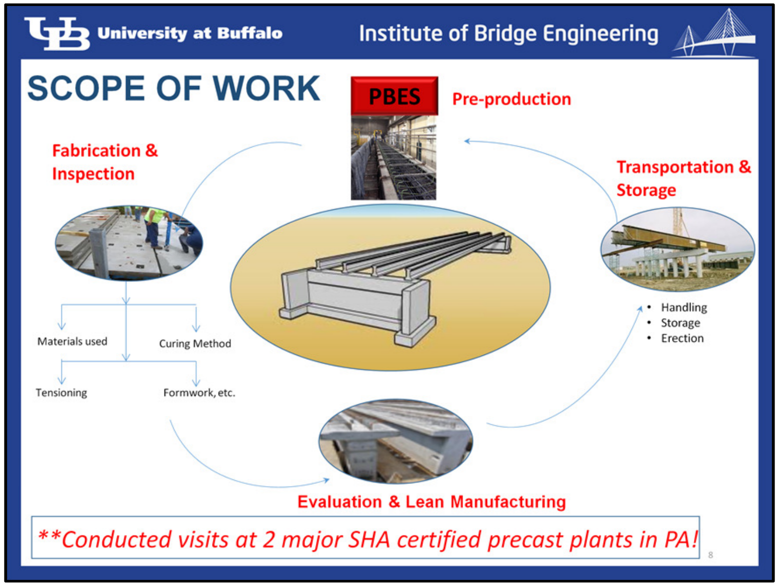
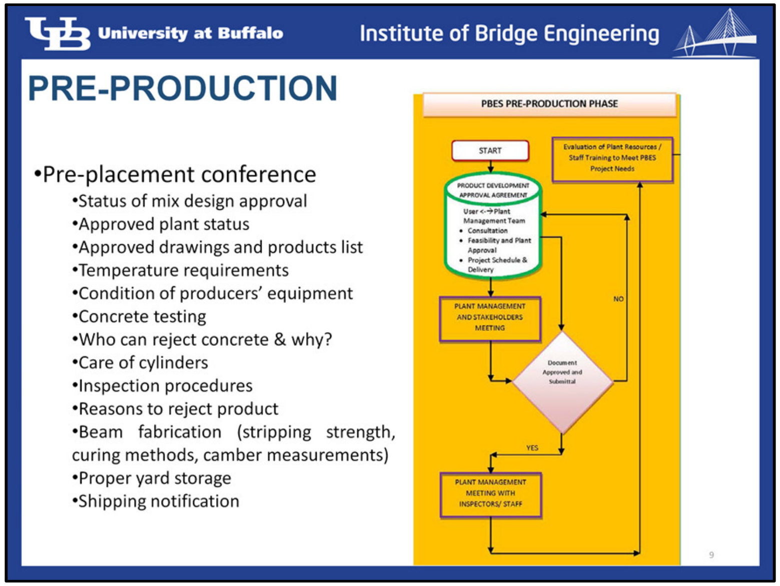


The process…
Precast concrete products used for accelerated bridge construction (ABC) are usually made-toorder for a specific project. Yet, the manufacturing process of these products is sometimes complex as human, materials and mechanical components must be managed concurrently and be quickly integrated 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.)

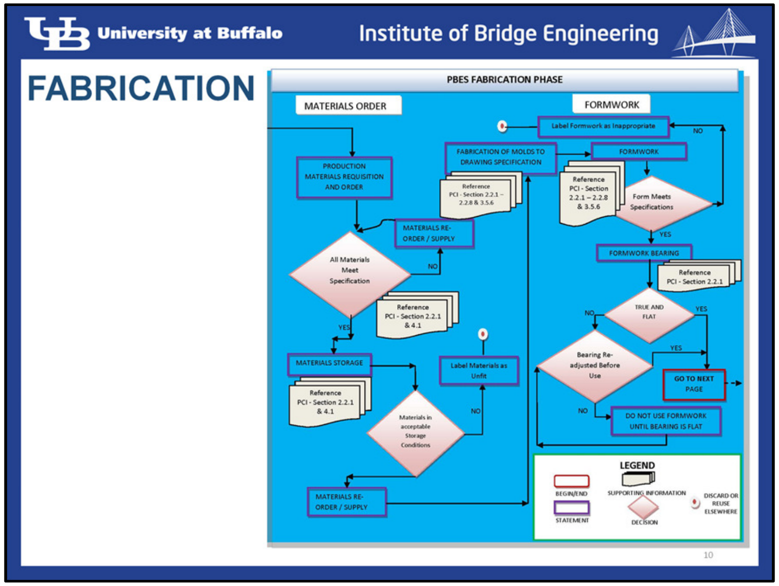


Based on what comes in and what goes out…
"Garbage in…garbage out…"
Status of Mix Design Approval
B. Approved Plant Status
C. Have Drawings been approved
D. Are all items on Qualified Products List
E. Temperature Requirements
F. Condition of Producers Equipment and Backup Equipment

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

40
G. Concrete Testing
H. Who has Authority to reject concrete and for what reasons?
a. Slump/Flow
b. Air Content
c. Time
d. Temperature

e. Water / cement ratio
f. Gradations (frequency guide)
g. Moistures (frequency guide)
I. What Procedure should be followed for failing slump
J. What Procedure should be followed for failing air
K. Brand and Type of Admixture, must be pre-approved
L. Have adequate provisions been made for curing
M. Care of cylinders and number of cylinders required
N. Anticipated start date of work
a. Request for inspection
b. Direct inspection facilities
O. Discuss procedure following beam fabrication
a. Required stripping strength
b. Curing methods
c. Camber measurements
P. Proper storage in yard
Q. Shipping notification
R. 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



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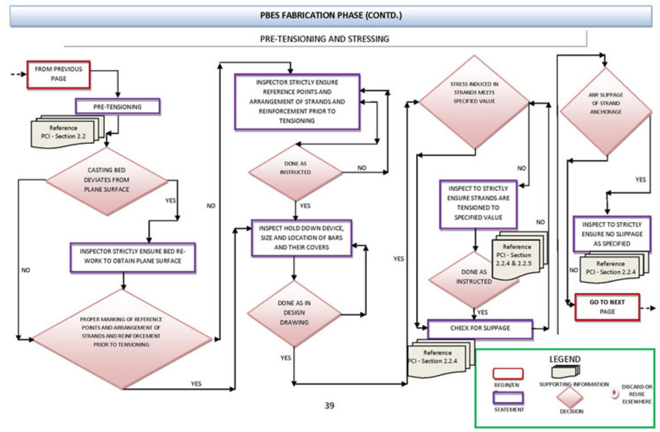
FABRICATION



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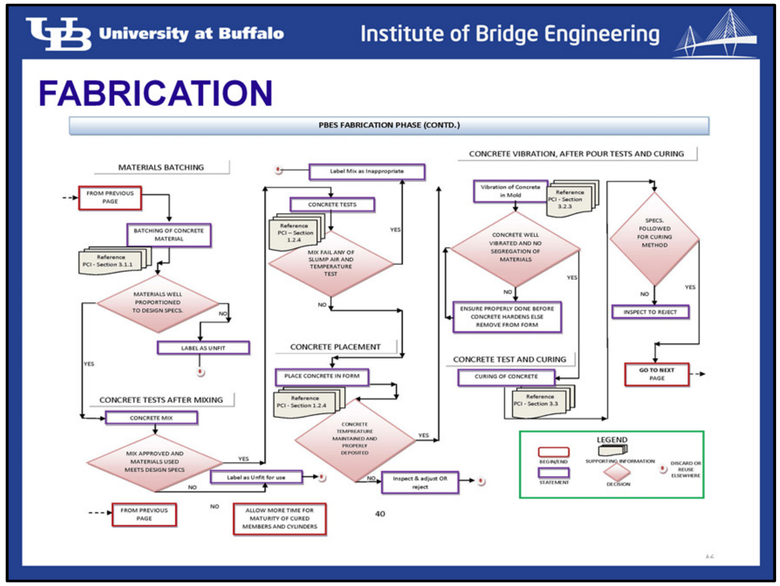

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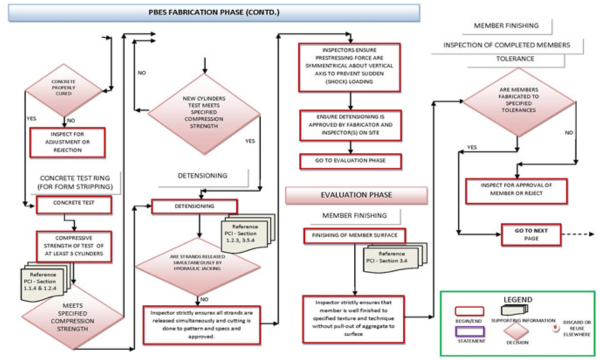
FABRICATION
PBES FABRICATION PHASE (CONTD.)
MATERIALS BATCHING
FROM PREVIOUS PAGE
BATCHING OF CONCRETE MATERIAL
Reference PCI - Section 3.1.1
MATERIALS WELL PROPORTIONED TO DESIGN SPECS.
NO
LABEL AS UNFIT
YES
CONCRETE TESTS AFTER MIXING
CONCRETE MIX
MIX APPROVED AND MATERIALS USED MEETS DESIGN SPECS
YES
Label as Unfit for use
NO
FROM PREVIOUS PAGE
NO
ALLOW MORE TIME FOR MATURITY OF CURED MEMBERS AND CYLINDERS
Label Mix as Inappropriate
CONCRETE TESTS
Reference PCI – Section 1.2.4
MIX FAIL ANY OF SLUMP AIR AND TEMPERATURE TEST
YES
NO
CONCRETE PLACEMENT
PLACE CONCRETE IN FORM
Reference PCI - Section 1.2.4
CONCRETE TEMPREATURE MAINTAINED AND PROPERLY DEPOSITED
YES
NO
Inspect & adjust OR reject
40
CONCRETE VIBRATION, AFTER POUR TESTS AND CURING
Vibration of Concrete in Mold
Reference PCI - Section 3.2.3
CONCRETE WELL VIBRATED AND NO SEGREGATION OF MATERIALS
YES
NO
ENSURE PROPERLY DONE BEFORE CONCRETE HARDENS ELSE REMOVE FROM FORM
CONCRETE TEST AND CURING
CURING OF CONCRETE
Reference PCI - Section 3.3
SPECS. FOLLOWED FOR CURING METHOD
NO
YES
INSPECT TO REJECT
GO TO NEXT PAGE
LEGEND
BEGIN/END
SUPPORTING INFORMATION
DISCARD OR REUSE ELSEWHERE
STATEMENT
DECISION

FABRICATION



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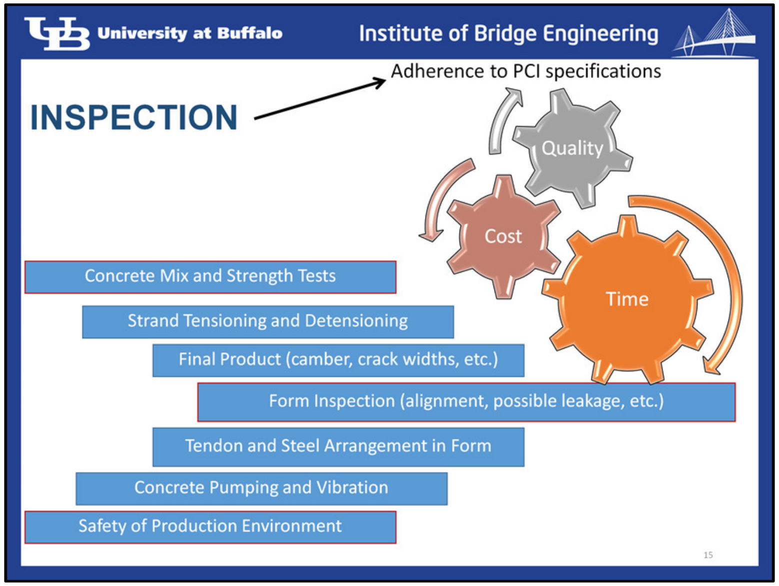
Lead to whole notion of lean manufacturing…
Eight types of waste were identified, resulting from mapping and classification of processes in plants and provision of verifiable tools to improve productivity. According to Ray et al. (2006), leveraging the principles of lean manufacturing could help achieve 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.

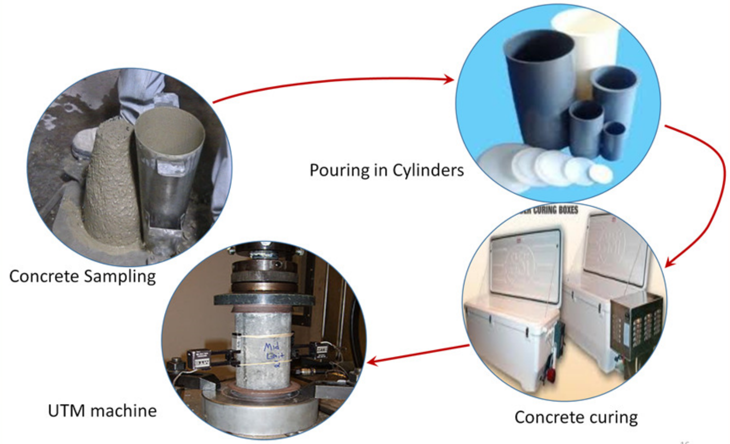
Lean manufacturing also facilitates fast and cost-effective implementation by accelerating production decision cycle, engagement of all employees in the continuous improvement process, and acting on opportunities for improvement, while ensuring optimal productivity throughout the product chain network. 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,

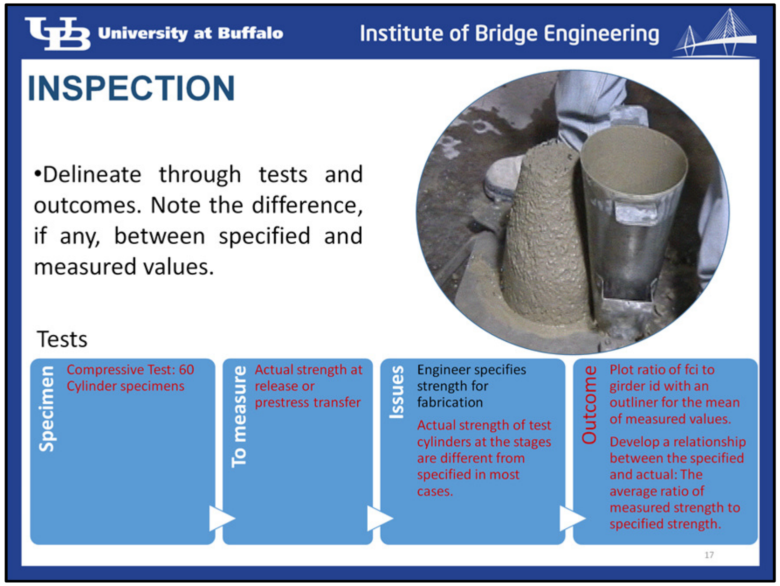
minimize waste, and improve overall efficiency at a precast plant.



Production and storage processes that undermine quality and cost savings

INSPECTION


Pouring in Cylinders
Concrete Sampling
UTM machine
Concrete curing



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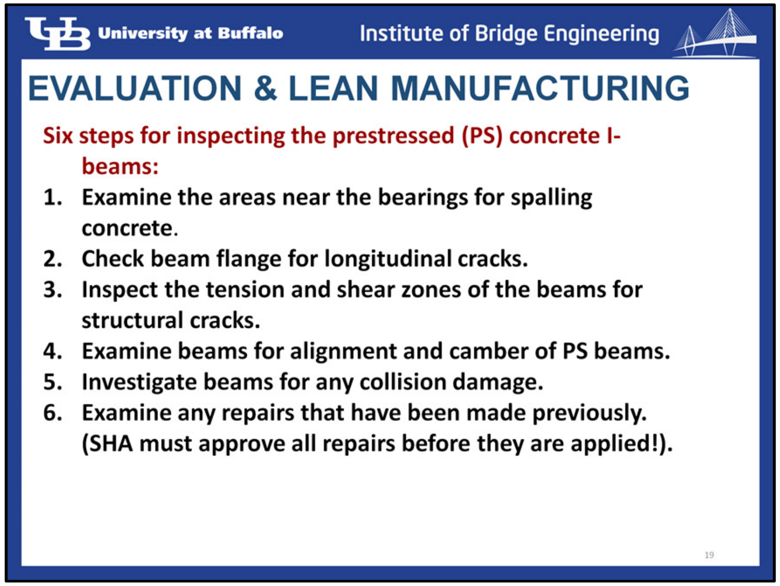
During the visual inspection process, it was noted that a few of the ties for the reinforcement strands had loosened before concrete pour. This issue was noted and corrected. A technician adjusted the beam along its length to ensure accurate cover was achieved. The reinforcement bars were all epoxy-coated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

To inspect the tensioning process, photos were taken to show how the strands were tensioned 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.



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EVALUATION – BEAM END CRACKS

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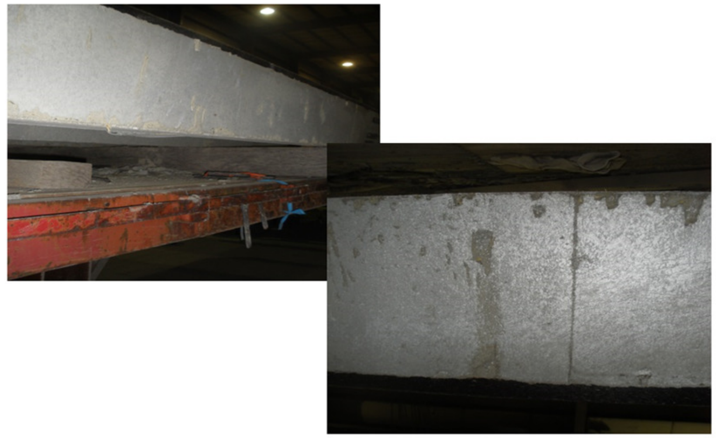

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EVALUATION – FINISHED PRODUCT

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EVALUATION – CRACK LOCATIONS

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

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EVALUATION – CRACK WIDTH AND LENGTH

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

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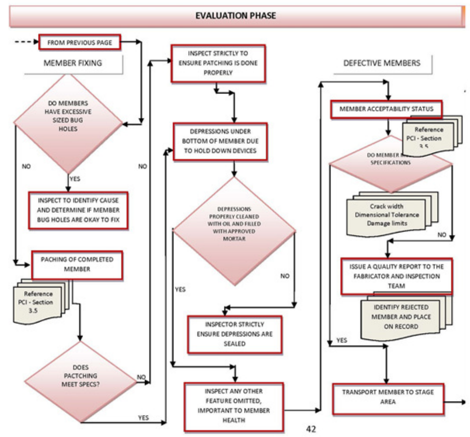
EVALUATION – CRACK WIDTH



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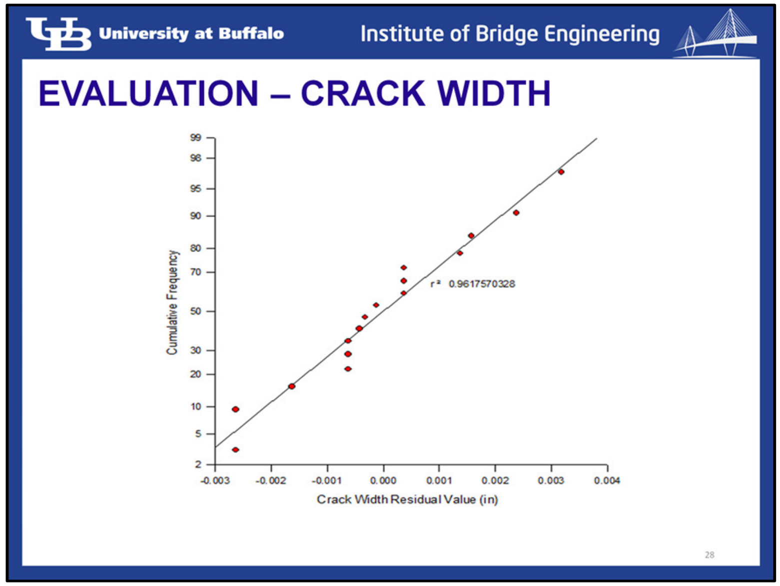
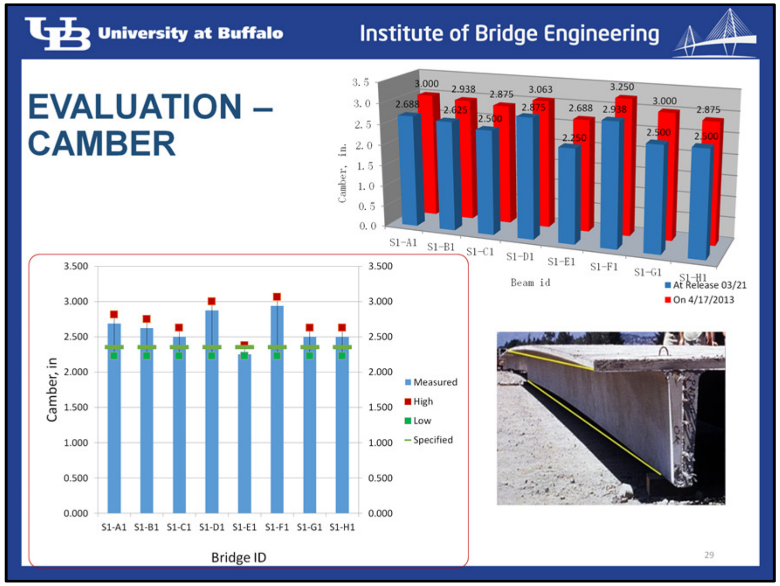


A t-test analysis of data obtained on crack width and camber was performed to investigate the difference between the specified and measured data using SigmaPlot. Based on crack width the following information was processed to conduct the first t-test:

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 of the frequency of the raw data 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.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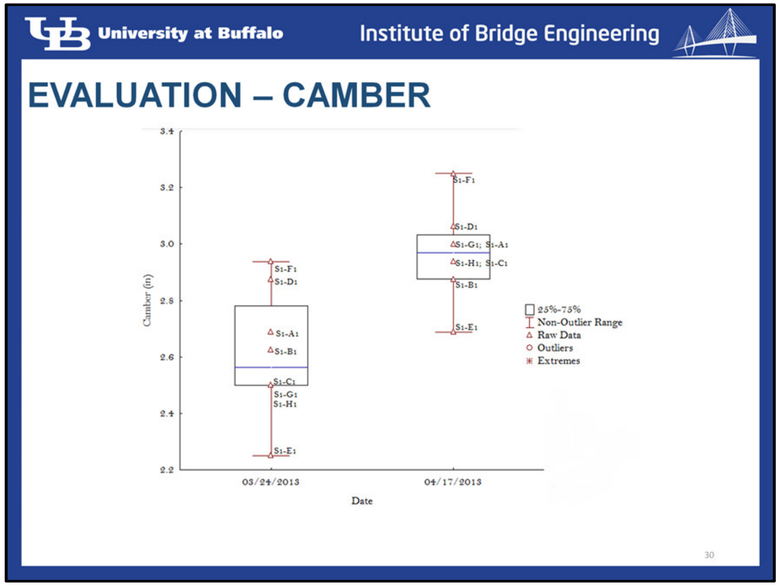
EVALUATION – CAMBER
Camber, in.
S1-A1 S1-B1 S1-C1 S1-D1 S1-E1 S1-F1 S1-G1 S1-H1
Beam id
At Release 03/21
On 4/17/2013
Camber, in
Measured
High
Low
Specified
Bridge ID
29



At release, camber measurements showed that majority of the beams have values that are below the specified value as seen in Figure 14 above. The sway of the data is shown as having the bottom whisker higher than the top whisker. Camber values for beams S1-H1, S1-G1, S1-D1 and S1-F1 are above the specified value of 2.35-in. while the lowest camber value was recorded for beam S1-E1. Twenty-five percent (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. Seventy-five percent (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 have values that are within close range (±0.05in) of the specified. The majority of the beams that 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.

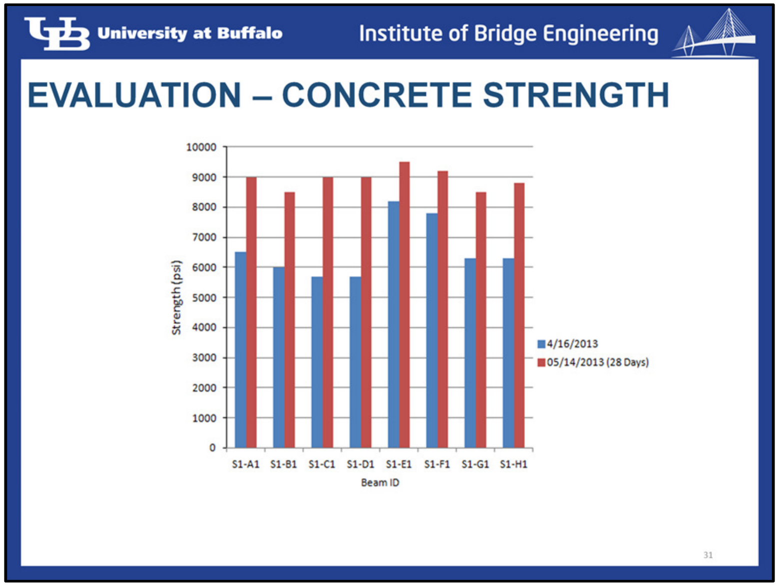
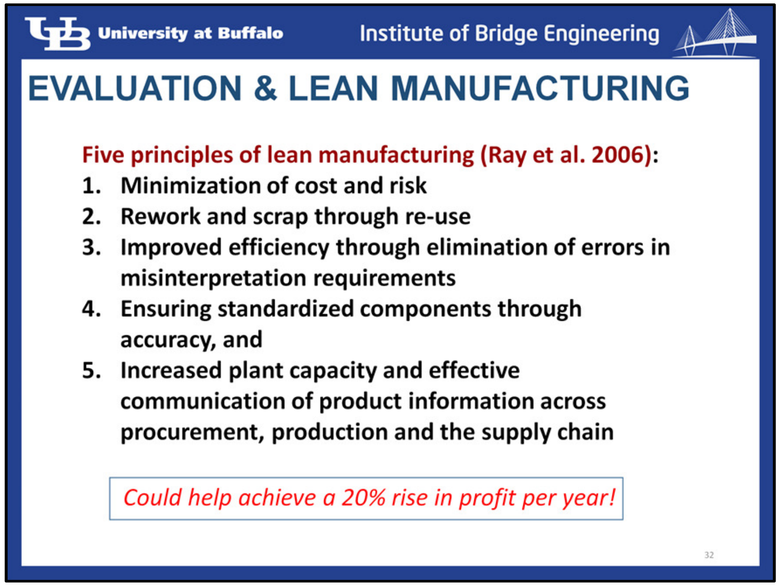


Figure 15 shows the concrete strength of the girders tested at the precast plant. The blue and red bar graphs show the compressive strength specified on 04/16/2013 and 05/14 /2013 as 5000psi and 7,000psi respectively. The compressive strengths were above the specified minimum compressive strengths for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



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EVALUATION & LEAN MANUFACTURING

Lean indices based on 5 categories (Ray et al. 2006):

1. **Waste minimization, warehouse safety/cleanliness**
2. **Product turnover**
3. **Dimension and tolerance**
4. **Material inventory**
5. **Storage**

Higher index indicates more leanness!

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

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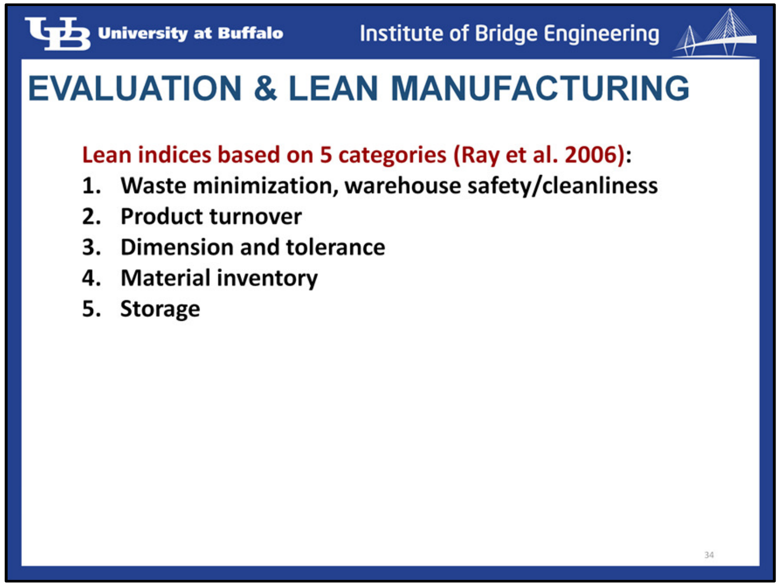

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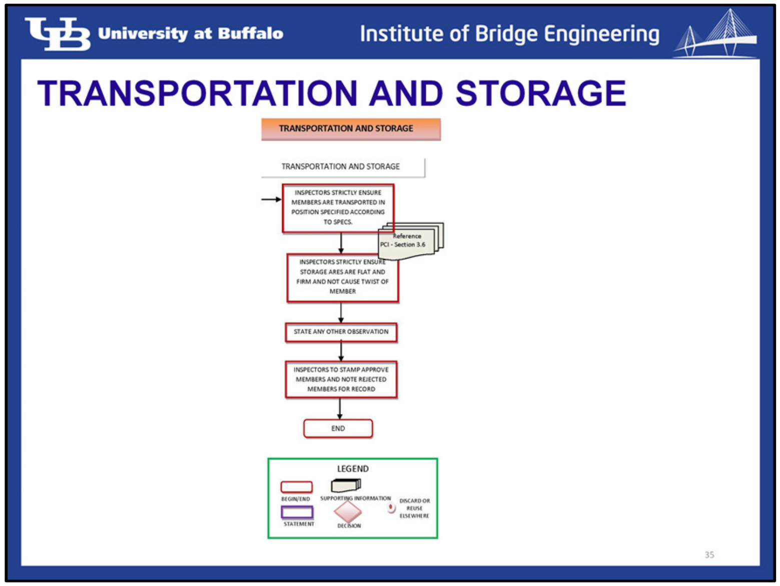

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TRANSPORTATION AND STORAGE
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INSPECTORS STRICTLY ENSURE MEMBERS ARE TRANSPORTED IN POSITION SPECIFIED ACCORDING TO SPECS.
Reference PCI - Section 3.6
INSPECTORS STRICTLY ENSURE STORAGE ARES ARE FLAT AND FIRM AND NOT CAUSE TWIST OF MEMBER
STATE ANY OTHER OBSERVATION
INSPECTORS TO STAMP APPROVE MEMBERS AND NOTE REJECTED MEMBERS FOR RECORD
END
LEGEND
BEGIN/END
SUPPORTING INFORMATION
DISCARD OR REUSE ELSEWHERE
STATEMENT
DECISION
35

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 of the frequency of the raw data 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.

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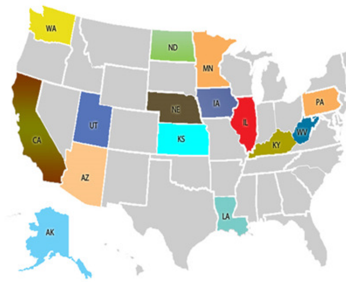

- 32 respondents
- Varying responses/cross-section

- Connecticut Department of Transportation
- Louisiana Department of Transportation and Development (LA DOTD)
- Slaw Precast
- Arizona Dept. of Transportation (ADOT)
- Caltrans METS
- NDDOT
- Iowa DOT
- ILL Depart of Transportation
- Kansas DOT
- Utah DOT
- State of Maine Department of Transportation
- WVDOT
- Central Atlantic Bridge Associates
- Northeast Prestressed Products
- Washington State DOT
- KY Department of Highways
- Minnesota DOT - Bridge Office
- North Dakota Department of Transportation
- State of Alaska Dept. of Transportation and Public Facilities
- **Saskatchewan Highways and Infrastructure**
- Nebraska Department of Roads
- PennDOT

http://www.surveymonkey.com/s/PJKHRDD

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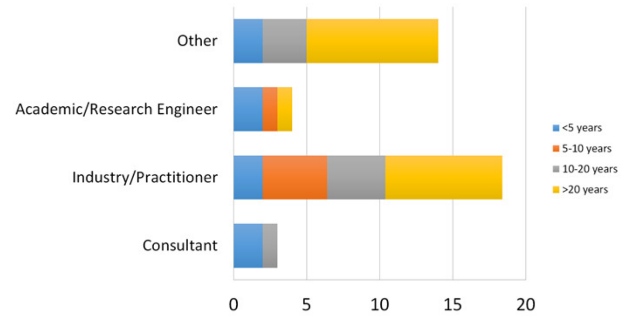
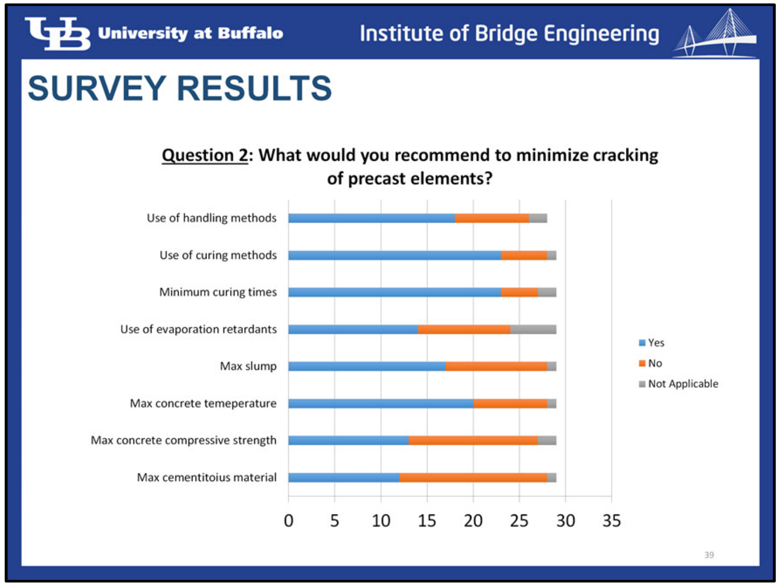
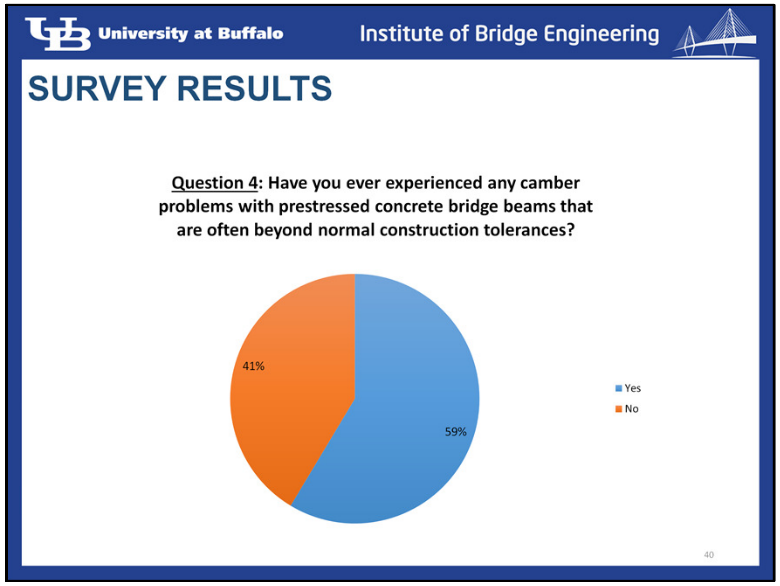
SURVEY RESULTS

Question 1: Which best describes your occupation and years of experience?





Trying to gage quality of product/ variations to address material control…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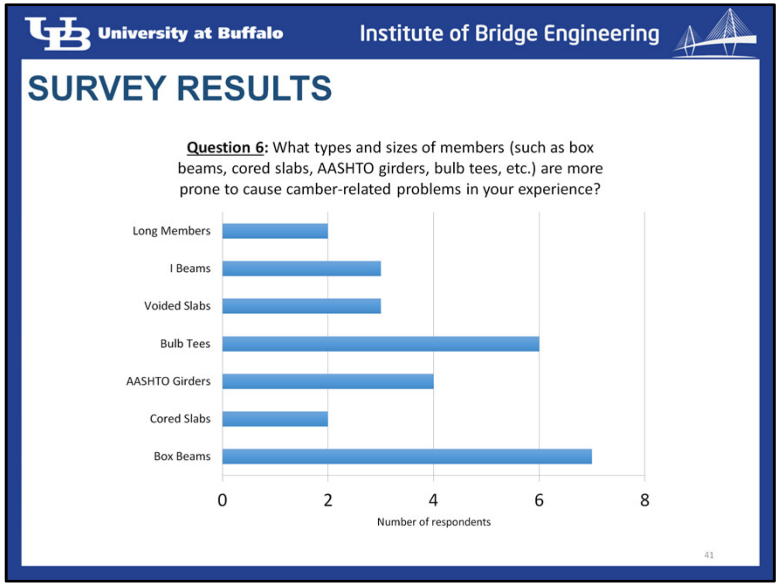
SURVEY RESULTS
Question 4: Have you ever experienced any camber problems with prestressed concrete bridge beams that are often beyond normal construction tolerances?
41%
59%
Yes
No
40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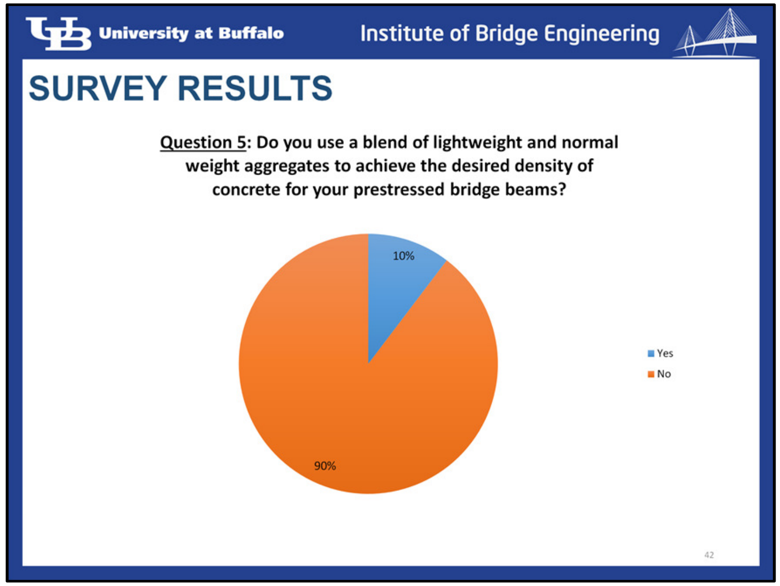
SURVEY RESULTS
Question 6: What types and sizes of members (such as box beams, cored slabs, AASHTO girders, bulb tees, etc.) are more prone to cause camber-related problems in your experience?
Long Members
I Beams
Voided Slabs
Bulb Tees
AASHTO Girders
Cored Slabs
Box Beams
0
2
4
6
8
Number of respondents
41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SURVEY RESULTS
Question 5: Do you use a blend of lightweight and normal weight aggregates to achieve the desired density of concrete for your prestressed bridge beams?
10%
90%
Yes
No
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PURPOSE OF THE PBES DATABASE

- To create a central location where contractors/ inspectors can enter data that has been collected from the different phases of construction/inspection.
- To use as an archive for PBES information and data collection.
  - General Input
  - Inspection Input
- To produce a summary of all the tasks from data collected.
  - Completed Task
  - Incomplete Tasks
- To assist in the evaluation and efficiency of the assembly process.

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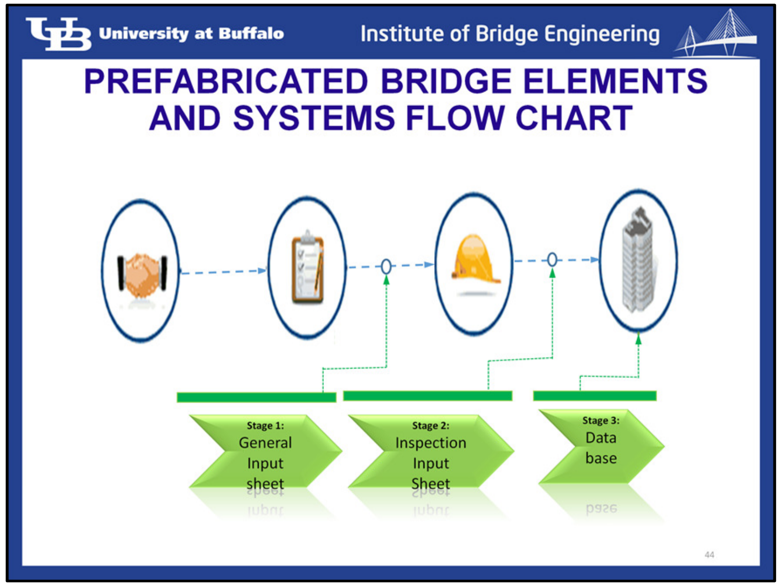
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PREFABRICATED BRIDGE ELEMENTS AND SYSTEMS FLOW CHART
Stage 1:
General Input sheet
Stage 2:
Inspection Input Sheet
Stage 3:
Data base
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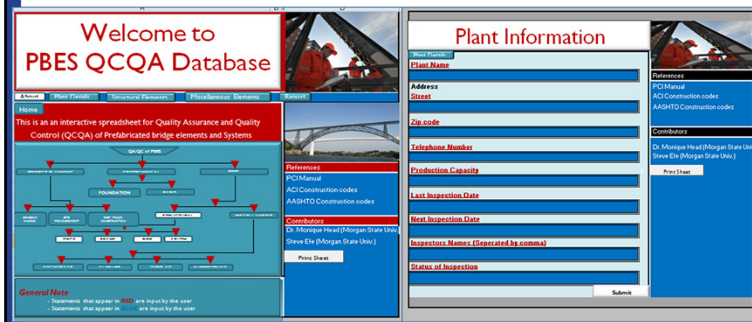
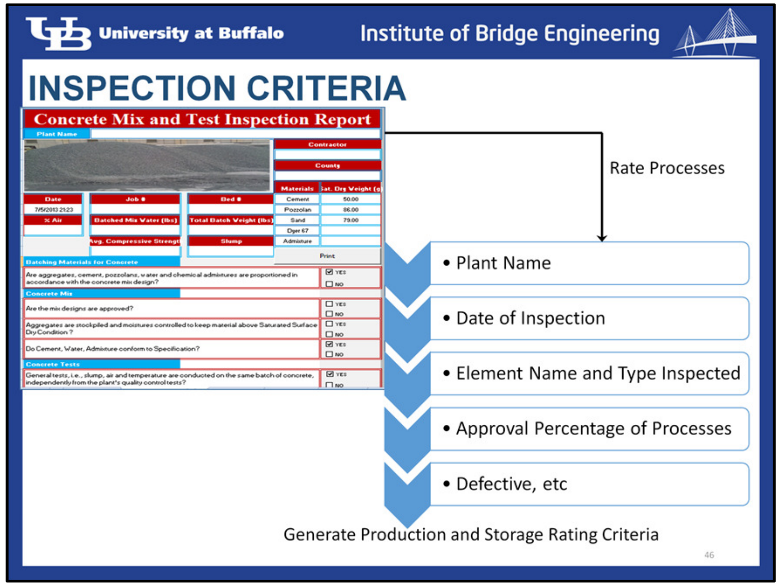


Click here to access database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INSPECTION CRITERIA
Concrete Mix and Test Inspection Report
Plant Name
Contractor
County
Materials
Sat. Dry Weight (g
Date
7/5/2013 21:23
Job #
Bed #
Cement
50.00
Pozzolan
86.00
Sand
79.00
Dyer 67
Admixture
% Air
Batched Mix Water (lbs)
Total Batch Weight (lbs)
Avg. Compressive Strengt
Slump
Print
Batching Materials for Concrete
Are aggregates, cement, pozzolans, water and chemical admixtures are proportioned in accordance with the concrete mix design?
YES
NO
Concrete Mix
Are the mix designs are approved?
Aggregates are stockpiled and moistures controlled to keep material above Saturated Surface Dry Condition ?
Do Cement, Water, Admixture conform to Specification?
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?
Rate Processes
• Plant Name
• Date of Inspection
• Element Name and Type Inspected
• Approval Percentage of Processes
• Defective, etc
Generate Production and Storage Rating Criteria
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PBES TUTORIAL

- These instructions apply to both input tabs
  - General Input Tab
  - Inspection Input Tab

<u>Input Tabs</u>

- All of the data that is input into this database is protected
  - NO Password needed
- Navigation Button
  - Four arrows located at the top-right of the database
    - First arrow allows users to view the first entry to be entered into the system.
    - Second arrow allows users to view the previous entry that was entered into the system.
    - Third arrow allows users to view the next entry that follow the one that is being viewed.
    - Fourth arrow allows users to view the very last entry that was entered into the system.

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PBES TUTORIAL

- Print Selection Button
  - Activate the nearest computer printer within the area, and print the necessary information requested
- Get to Specific Records
  - Select the desired Project ID from the drop box list in cell J3, so the user can view the entire project scope
- To Update and Add Records
  - Using the arrow that were discussed earlier, select an entry from the saved records and edit it. After finishing editing, click on the ***update*** button to revise the changes made to the section.
  - Starting with a blank form, enter the new data into the particular section which correspond with the actual document used in the field to record the data.
    - Once you are done with entering the new information in the correct segment, click the ***add*** button to store and save the new information into the database.

Note: Warning alerts will appear if a user is trying to enter an exact ID number that is already saved into the system or if a user is trying to update information that is not already saved into the system.

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DATABASE CONTENT

- Instructions
  - Introduce the system and its capabilities.
  - Illustrates how the database is intertwined logically (demonstrated by a flow chart)
  - Inform the user on the different button functions that are important to when a user is entering data.

DATABASE CONTENT

- General Inputs
  - Sections are broken down into specific categories that match the different inspection forms.
  - Provides the user with a source of references to help guide the operators on how to maneuver through the program.
  - From General Information to Lab Results, General Input is the section where the data collected in the field can be found.

DATABASE CONTENT

- Inspection Inputs
  - Data that is reflected in the database was input by Morgan State University’s contributors from different sites where prefabricated beams were fabricated.
  - Inspection data is from the inspector who has examined the material in person and document the results.
  - Inspection Input is the information collected by the inspector as the different phases are being tested in different conditions.

DATABASE CONTENT

- Summary
  - Sum up all of the subsection within the different section in the General Input and Inspection Input
  - These summations are demonstrated by graphs
  - Help to see the overall picture of what is doing well and what needed to be improved soon.
    - On-site Data
    - Off-site Data

SUMMARY OF FINDINGS

- Suggestions for waste minimization practices were recommended and included examples 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.
- To assist with QA/QC process improvement procedures, keeping *camber measurements and crack openings within acceptable tolerances are critical since cracks* can grow as a result of differential shrinkage and creep, which in turn, can lead to the potential ingress of moisture and other deicing salts that necessitate corrosion. 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.

SUMMARY OF FINDINGS

- 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
- 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.

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SUMMARY OF FINDINGS

- Future work can consist of combining a previously funded SHA project titled, "*Radio Frequency Identification (RFID)," (see MD-14-SP209B4G Final Report: Utilizing Auto ID Tracking System to Compile OFS Data) and the inspection database created herein to maintain critical data and* track beams produced by each project. Having this structure and "reporting out system" will assist with 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 also 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 initial beam production 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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ACKNOWLEDGMENTS

Maryland State Highway Administration

Steve Efe, Doctoral Candidate
Ryan Wright, MS (graduated)
Siafa Grose, Doctoral Candidate
Isaac Mason, Doctoral Candidate
Ebony Ashby-Bey, undergraduate researcher (graduated)
Kyle Edmonds, undergraduate researcher (graduated)
Emani Evans, undergraduate researcher (Dec15 graduation)
Tyrone Hansboro, Jr., undergraduate researcher (graduated)
Darryl Burrell, undergraduate researcher

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THANK YOU!

Questions or Comments?

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