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Course Description

Benefits of Steel in Accelerated Bridge Construction

June 19, 2018

Accelerated Bridge Construction (ABC) has become commonplace in the United States. Prefabrication is the key to a successful project. The webinar will focus on the benefits of steel in ABC including reduced weight and the ability of the material to accommodate variable stresses during erection. Common forms of prefabrication using steel elements will be presented. Portions of the webinar will be based on the recently published reports for Projects 12-102 and 12-98 of the National Cooperative Highway Research Program (NCHRP).



Learning Objectives

- Describe accelerated bridge construction methods.
- List the advantages that steel has over other materials for accelerated bridge construction.
- Explain the purpose of a link slab and where on a bridge it might be used.
- Identify resources available to practitioners looking to employ accelerated bridge construction.



Benefits of Steel in Accelerated Bridge Construction



Presented by
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There's always a solution in steel.



Benefits of Steel in Accelerated Bridge Construction

Michael P. Culmo
CME Associates, Inc.



Current Status of ABC in the United States

- ABC has become commonplace
- Literally thousands of bridges have been built using ABC
- Prefabrication is the key
- Many people think of precast with ABC
- Steel has definite advantages over concrete in many cases



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Why consider Steel Elements?

Concrete elements can get very heavy

- Shipping limitations
- Crane limitations

Can accommodate lifting and handling forces

- Cracking of concrete has been problematic

Span/weight limitations of concrete beams

Connections can be faster

- Field bolting

Can be fabricated to a high degree of accuracy

- Improved fit-up in the field



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Bridge Systems

- Entire superstructure built off site
- Set on existing or new substructures built under the bridge
- Two most common approaches
 - Self Propelled Modular Transporters (SPMTs)
 - Lateral Slide



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SPMT Bridge Moves with Steel

- **SPMT Bridge Moves**
 - Steel is lighter than concrete
 - Steel can handle large force/moment reversals



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SPMT Bridge Moves

Designer Responsibilities

- Design the bridge for final configuration
 - Identify pick points
 - Determine allowable twist, differential support elevations
 - Analyze and design the bridge for lift at pick points
 - State lifting loads on plans
- Preliminary SPMT Investigation
 - Preliminary SPMT layout
 - Staging area and travel path investigation
 - Check for flatness



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SPMT Bridge Moves

Contractor Responsibilities

- Design of temporary supports in staging area
- Final SPMT layout and travel path check
- Design of all falsework
- Design of monitoring system (if specified)
- Analyze the bridge if the final pick points need to move
 - Based on final SPMT layout or travel path issues



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SPMT Bridge Moves with Steel

Construction Method

- Build bridge off-site on temporary abutments
- Lift bridge with SPMTs
 - **Away from supports**
- Move into place
- Set on new substructure
- Imparts significant bending moments in the beams



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Bridge Systems using Steel Beams

Construction Stage	System Support Sketch	System Moment Diagram	Deck Moment Diagram
Girder & Deck Placement			
Composite Dead Loads			
After lift by SPMT			
After Setting			

Pick points

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Bridge Systems using Steel Beams

Effect of Bridge Weight on SPMT moves

- Heavier bridges require more SPMT axles lines
 - Roughly 60k per axle line (single wide)
- Heavier bridges require larger falsework
 - Vertical Load
 - Lateral loads?

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NCHRP Project 12-98 – Dynamics of SPMTs

Studied Dynamic Effects during Bridge Moves

- What happens to the bridge and falsework during the actual move
 - Bouncing?
 - Starting and Stopping?
 - What is the effect of weight?
- This research project investigated all of this

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NCHRP Project 12-98 – Dynamics of SPMTs

Research Hypothesis

- An SPMT move is akin to a manmade earthquake
 - The SPMT platform is the earth
 - Movements generate accelerations and decelerations
 - These are imparted on the bridge and falsework
- Test approach
 - Place various loads on an SPMT with accelerometers
 - Drive the unit through various maneuvers
 - Measure accelerations
 - Determine affect of weight and stiffness of the system

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NCHRP Project 12-98 – Dynamics of SPMTs

Test Set-Up

- 3 loads
- 15% capacity
- 25% capacity
- 50% capacity
- Set pattern of movements

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NCHRP Project 12-98 – Dynamics of SPMTs

Typical test

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NCHRP Project 12-98 – Dynamics of SPMTs

Response spectrum curves developed for vertical and horizontal dynamics

Vertical Acceleration Design Spectrum

Horizontal Acceleration Design Spectrum

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NCHRP Project 12-98 – Dynamics of SPMTs

Results

- There are significant lateral forces acting on the bridge and falsework during the move
- The forces are correlated with the weight of the bridge and the stiffness of the bridge and falsework
- Similar to seismic
- What about steel bridges?
 - Lower weight will reduce the number of axles requires (saves \$\$)
 - Lower lateral forces in falsework (saves \$\$)
 - Lower weight reduces the vertical forces acting on the beams and deck

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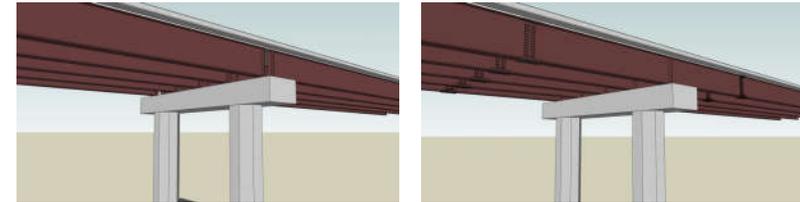
Prefabricated Elements

- Portions of the bridge built off site
- Connected together in the field
- Requires smaller equipment
 - Still very heavy equipment
- Steel Modular Deck Beam Elements (MDBEs) are popular
 - Why?
 - Less weight
 - Smaller cranes



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Simple Spans vs. Continuous Spans



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Conventional Construction (since 1950s)

What we were taught in school

- Least weight = Least Cost
- Continuity is better
 - Uses less structural steel
 - Elimination of deck Joints and associated deterioration
 - Fewer Bearings

Is this really true?

- What is the true cost of a girder?
 - Fabrication
 - Transport and erection
 - Field work (splices)
 - Other items

Maybe we should look at the TOTAL cost of a bridge?



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Bridge Deck Expansion Joints

- Used to accommodate thermal movement
- Fact: Deck joints Leak (a lot)
- Leaking deck joints are the number one cause of bridge deterioration
- Most designers look to eliminate them
- Continuity has been the approach taken



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Why consider "Span-by-Span" Construction?

Prestressed Girders?

- Designers almost always use "Span-by-Span" construction due to difficulties with splicing concrete girders
- Why not for steel?

Accelerated Bridge Construction

- Make use of modular elements and "Span-by-Span" construction




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Uses of Span-by-Span Construction

Modular Deck Beam Elements







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Uses of Span-by-Span Construction

Modular Deck Beam Elements



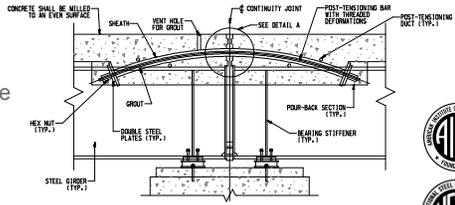



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What about deck joints?

How can we use Span-by-Span construction without joints?

- Simple for DL and continuous for Live Load
- Requires a bottom flange connection (closure pour or bolted splice)
- Concerns about forming time and alignment
- Complex details
- Deck cracking under Live load?
- More field work

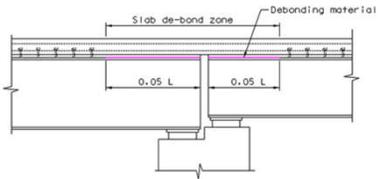





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Link Slab Design

- Another option
- Jointless, not continuous
 - Less complicated
 - Less Expensive
- Used to accommodate the end rotations in the beams



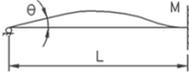
Note: L = Span Length of beams on either side of the pier




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Link Slab Design

- Theory
- Based on research
 - "Behavior and Design of Link Slabs for Jointless Bridge Decks", PCI Journal, May-June 1998



$$M = 2 EI \theta / L$$

θ = Girder end rotation
 L = debond length
 E = modulus of elasticity of link slab
 I = Gross moment of inertia of slab




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Link Slab Design

What about skew?

- Research has shown that skew reduces beam end rotation
- Plate theory
- Deflection is more of a function of perpendicular span

Recommendation

- Calculate end rotation using the span length along the beams
- Conservative




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Link Slab Usage

Jointless decks are not new

- Common in precast construction

Texas

- Use of slab over piers without a specific link slab design
- Used for many years
- Great performance

Connecticut and Massachusetts

- Similar to Texas

Other states




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Completed Link-Slab Bridge



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Feasibility Study

Cost Comparison

- Simple spans with link slabs versus continuous Spans
- Look at total bridge costs
- Consider the following:
 - Steel weight
 - Fabrication costs
 - Cost for field splices
 - Bearings
 - Erection and handling methods
 - Deck reinforcement

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Trial Bridge

Two span: 122'-122'
5 Girder Lines
8'-3" Girder Spacing



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Trial Bridge

Continuous Girder Details

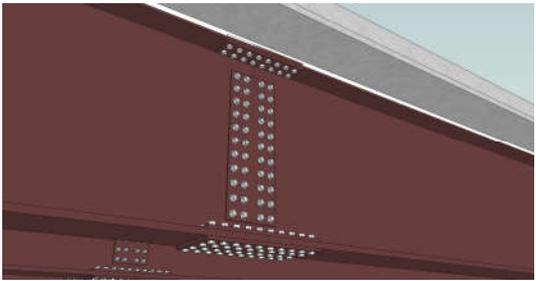


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Trial Bridge

Continuous Girder Details



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Trial Bridge

Simple Span Girder Details



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Trial Bridge

Simple Span Girder Details



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Design:

Girder Design: Used the NSBA Program
SIMON

LRFD Design
Girder optimization
Cost analysis

- Applied different costs to:
 - Webs, Flanges, and Stiffeners

Bolted Splice Design

- Locate near DL inflection points
- Used NSBA Program: NSBA Splice

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Cost analysis: Continuous Bridge

- Steel Weight: 143 Tons (SIMON output)**
- Steel Fabrication Cost:**
 - Flanges: \$1.13 per pound
 - Webs: \$0.97 per pound
 - Stiffeners: \$2.00 per pound
- Total Steel Cost: \$310,635**
Note: Costs vary greatly by region

Assumed Unit Costs

Fy:	36	42	50	70	90-100	Ksi
Cost:	992.00	0.00	1088.00	0.00	0.00	\$/tons

Assumed Fabrication Factors

Web:	1.79
Flanges:	2.08
Web L.S.:	4.03
Web T.S.:	3.66
Flange Tees:	4.33

ESTIMATED GIRDER COST (\$)

Span	Web	Flanges	Web L.S.	Web T.S.	Flange Tees	Totals	
1	9016	21502	0	151	0	30669	
						Bearing stiffeners	788
						Girder Cost	62127
						Total Estimated Bridge Cost	310635



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Cost analysis: Continuous Bridge

- Negative Moment Region Deck Reinforcing**
 - Area of reinforcing per beam: 9.55 in² per beam
 - Approximate length of neg. moment region = 74 feet
 - Total weight of reinforcing needed = 12,000 pounds
 - Cost of extra reinforcing: \$24,000



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Cost analysis: Continuous Bridge

- Bolted Splice**
- 116 Bolts
- Assume \$50 per bolt
- Cost: \$5800 per splice

4 rows of 4 @ 3 in

7/8 in AASHTO M154 BOLTS (AASHTO Flange) (AASHTO Web) Facing Surface Class = B

PERFORMANCE RATIOS (P/R):

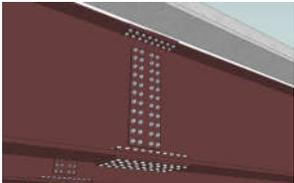
Top Flange Splice:	1.02
Top Flange Plate:	0.99
Bottom Flange Bolt:	0.99
Bottom Flange Plate:	0.99
Web Bolt:	0.99
Web Plate:	0.91

Top Flange Splice Bolt: 10.750 x 14 - 24.5
Bottom Flange Splice Bolt: 10.750 x 14 - 24.5
Web Splice Bolt: 10.750 x 14 - 24.5

Top Flange Plate: 1 x 0.875 x 14 - 30.5
Bottom Flange Plate: 2 x 0.375 x 14 - 40.75
Web Plate: 2 x 0.875 x 7 - 30.5

3.75in Spacing

Adjust Design: View, Report, Print, Splice, Exit





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Cost analysis: Continuous Bridge

- Total Costs**

2 Span Continuous				
Item	Units	Quantity	Unit Cost	Cost
Steel Cost	Tons	143	by program	\$310,635.00
Addl. Deck Reinforcing	Pounds	12000	\$2.00	\$24,000.00
Bearings	Each	15	\$300.00	\$4,500.00
Bolted Splice	Each	10	\$5,800.00	\$58,000.00
Shoring Towers	Each	2	\$10,000.00	\$20,000.00
			Total	\$417,135.00



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Cost analysis: 2 Simple Spans w/ Link Slab

- Steel Weight: 173 Tons (SIMON output)
- Steel Fabrication Cost:
 - Flanges: \$1.13 per pound
 - Webs: \$0.97 per pound
 - Stiffeners: \$2.00 per pound
- Total Steel Cost: **\$381,696**
Note: Costs vary greatly by region

Assumed Unit Costs						
Fy:	36	42	50	70	90-100	Ksi
Cost:	992.00	0.00	1088.00	0.00	0.00	\$/tons

Web:	1.79
Flanges:	2.08
Web L.S.:	4.03
Web T.S.:	3.66
Flange Tees:	4.33

Span	Web	Flanges	Web L.S.	Web T.S.	Flange Tees	Totals
1	8666	28911	0	198	0	37776
Bearing stiffeners						394
Totals	8666	28911	0	198	0	38170
Girder Cost						38170
Total Estimated Bridge Cost						190848




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Cost analysis: 2 Simple Spans w/ Link Slab

- Link slab reinforcing
 - Area of reinforcing per beam: 3.30 in² per beam
 - Approximate length of link slab region = 8.5 feet
 - Total weight of reinforcing needed = 1,000 pounds
 - Cost of extra reinforcing: \$2,000




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Cost analysis: 2 Simple Spans w/ Link Slab

- Total Costs

2 Simple Spans with Link Slabs				
Item	Units	Quantity	Unit Cost	Cost
Steel Cost	Tons	173	by program	\$381,696.00
Addl. Deck Reinforcing	Pounds	1000	\$2.00	\$2,000.00
Bearings	Each	20	\$300.00	\$6,000.00
Bolted Splice	Each	0	\$5,800.00	\$0.00
Shoring Towers	Each	0	\$10,000.00	\$0.00
			Total	\$389,696.00




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Cost Comparison

Item	Continuous Spans	Simple Spans
Steel Cost	\$310,635.00	\$381,696.00
Addl. Deck Reinforcing	\$24,000.00	\$2,000.00
Bearings	\$4,500.00	\$6,000.00
Bolted Splice	\$58,000.00	\$0.00
Shoring Towers	\$20,000.00	\$0.00
Total	\$417,135.00	\$389,696.00





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Available Resources

NCHRP Project 12-98: Dynamics of Bridge Systems

- Report and Dynamic Guideline available at NCHRP website
 - Search: [NCHRP Project 12-98](#)

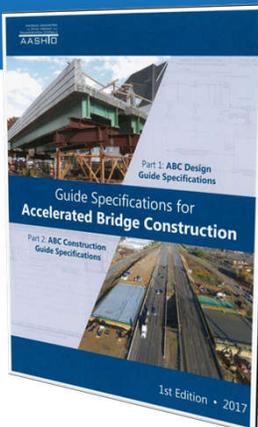


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Available Resources

NCHRP Project 12-102: Development of ABC Guide Specs

- Report available at NCHRP website
 - Search: [NCHRP Project 12-102](#)
- AASHTO ABC Guide Specs to be published in 2018



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Conclusions

Steel beams are inherently lighter than concrete beams
Reduced weight is beneficial with ABC

- Fewer SPMT axles
- Lower forces during move
- Smaller cranes for prefabricated elements

Steel beams can accommodate lifting forces

- Especially negative bending moments

Span-by-Span construction works well with ABC

- Link slabs are the key
- Modular steel beam units are very versatile
- Weekend construction is very reasonable



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Questions?



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