CASE STUDY:
SR 228 OVER BREAKNECK CREEK

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1. Project Introduction
2. Project Evolution & Alternates
3. Constructability & Design-ability
4. Identified Removal Limits
5. Identified Construction Sequence
6. Complex Reinforcement Layout
7. Detailing Examples
PROJECT INTRODUCTION
SR 228 Corridor Improvement
PennDOT District 10-0
Adams Township in Butler County
Project to widen corridor
Replace structurally deficient bridge over CSX Railroad
Extend existing concrete arch under approach to bridge
Arch is to the left side of the survey.

Bridge is to the right side of the survey.

Station ahead to the right.

Breakneck Creek flows generally north.

Entire arch extension and half of bridge constructed in Phase 1.
PROJECT INTRODUCTION

- Cast-in-Place Concrete Arch
- 55° Skew
- 75’-0” Out-Out Length
- Multi-Centered Arch
- 26’-9” Opening at Springline
- 6’-8” of Fill over Crown
- Arch 9” Thick at Crown

EXISTING ARCH PLAN
PROJECT INTRODUCTION

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EXISTING ARCH SECTION

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PROJECT EVOLUTION & ALTERNATES
Extension in Kind
Cast-in-Place
Match Opening
75’-0” Upstream
Friction Loss Doubles
Increases Water Surface Elevation
The original extension-in-kind concept causes increases to the 100-year flood water surface elevation upstream.

No water surface increases were tolerable.

To reduce the friction loss, arch opening had to be increased.
PROS:
- Faster Construction
- Familiar Method
- Potential Cost Saver

CONS:
- Skews are Limited
- Transition to Existing
- Without Good Tie-In, Must Replace Entire Arch
PROS:
- Precast Part Built Quickly
- C.I.P. Transition to Existing
- Fewer Skew Limitations

CONS:
- Transition End Shapes Set
- Potential Debris Catcher
- Two Construction Methods
- More Costly
PRECAST C.I.P. COMBINATION

ALTERNATE 2
Start with existing arch and end.

Remove existing spandrel wall.
Cast footings and pedestals.
Cast "overarch" to square end.
Tapered section to transition between openings.
Cover entire length with 30' precast arches.
Add spandrel wall.

**ALTERNATE 2**

**Shortcomings:**

- Excavate to expose top of arch.
- Remove existing spandrel & counterforts.
- Long stretch of costly precast.
- Tapered section and overarch difficult to cast.
- Tapered section does not fully remove blunt end.
Start with existing arch end. Remove existing spandrel wall. Cast footings and pedestals. Cast "overarch" to square end. Tapered section to transition between openings. Extend length with 30' precast arches. Add spandrel wall.

ALTERNATE 3

Shortcomings:

Excavate to expose top of arch. Remove existing spandrel & counterforts. Short stretch of costly precast. Tapered section and overarch difficult to cast. Blunt end removed by even more complex castings.
From: Flo Determiner  
Sent: Tuesday, September 23, 2014 12:24 PM  
To: David Miraglia  
Subject: SR 228 Arch Extension - WSEL

Dave,

We analyzed the hydraulic opening you provided, and unfortunately it is not large enough to avoid increases to the 100yr WSEL.

Please add additional opening area, or reduce the arch length.

Thanks,

Flo Determiner, PE  
Engineer | Hydraulics & Hydrology  
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Start with existing arch.

Remove existing spandrel wall.

Cast footings.

Cast "overarch" to square end.

Tapered section to transition between openings.

Extend length with 36' precast arches.

Add spandrel wall.

ALTERNATE 4

Shortcomings:

Excavate to expose top of arch.

Remove existing spandrel & counterforts.

Short stretch of costly precast.

Tapered section and overarch difficult to cast.

Tapered section does not fully remove blunt end.
Start with existing arch end.

Remove existing spandrel wall.

Cast footings and pedestals.

Cast "overarch" to square end.

Tapered section to transition between openings.

Extend length with 36' precast arches.

Add spandrel wall.

ALTERNATE 5

Shortcomings:

Excavate to expose top of arch.

Remove existing spandrel & counterforts.

Short stretch of costly precast.

Tapered section and overarch difficult to cast.

Blunt end removed by even more complex castings.
David Miraglia

From: Pat M. Bankment
Sent: Tuesday, September 23, 2014 12:24 PM
To: David Miraglia
Subject: SR 228 Arch Extension – Rdwy Staging

Dave,

I just got word from roadway that they need an additional lane in construction stage 1. Try not to excavate too much behind that existing headwall.

Thanks,

Pat M. Bankment, PE

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PROS:
- Few Design Limitations
- Can Skew to 55°
- Single Construction Method
- Minimal Removal of Existing

CONS:
- Slower Construction
- Unfamiliar Techniques
- Standard Arch Reinforcement Orientation
Start with existing arch end. Use existing spandrel wall as shoring. Cast footings. Cast wedge arch to square end. Tapered section to transition between openings. Extend length with 36' C.I.P. arch. Add spandrel wall.

ALTERNATE 6

Shortcomings:

Wedge arch and tapered section difficult to cast.

Each bar in wedge arch would be a different length.

Minimum fill over arch’s near right corner requires more ROW, creates unbalanced loading, and it is ugly.
Use existing spandrel wall as shoring.

Remove old wings & footings.

Cast footings.

Cast collar and tapered arch, with skewed end.

Extend length with 36' C.I.P. arch with skewed ends.

Add counterforts & spandrel wall.

Add wingwalls.

SELECTED ALTERNATIVE

Advantages:

Single method of construction.

A large crane is not required.

End of arch matches roadway skew.

Transition geometry simplified by basing proposed arch section on existing arch section.

Water eased through taper.
SELECTED ALTERNATIVE

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- Single method of construction.
- A large crane is not required.
- End of arch matches roadway skew.
- Transition geometry simplified by basing proposed arch section on existing arch section.
- Water eased through taper.
CONSTRUCTABILITY
& DESIGN-ABILITY
Skews are hard to build on, and in many cases harder to design.

But aligning the bars normal to the arch’s center-line creates many issues.

The “Typical” bars are only typical for a third of the arch length.
CONSTRUCTION & DESIGN

3D Drafting
Rule #1

If it is a pain to draw it will be a pain to build.

To allow the primary bars to follow the skew, the arch was designed along the skew.

So instead of designing a 36'-0” opening, a 43'-11½” span was used.
IDENTIFIED LIMITS OF REMOVAL
Construct Temporary Shoring

Construct Cofferdam

Excavate & Expose Wings

Remove Wings & Footings

Construct Proposed Footings

LIMITS OF REMOVAL
IDENTIFIED SEQUENCE OF CONSTRUCTION
Arch footings built first.

Segment C was built next so construction could move in both directions.

Segment B and the Spandrel Wall could now be formed and poured against Segment C.

Segment A was cast after so formwork could bridge between existing arch and hardened Segment B.
The wing stems could be cast at the same time as the tapered arch (Segment A).

FYI: Contractor chose to pour Segment B with Segment C, then pour Segment A, then the spandrel and wings.
The barrel’s circumference is over 55’, therefore the BC standards require at least one optional longitudinal construction joints.

Two joints keep a construction joint away from the arch crown.

Cut the arch approximately in thirds, then add a joint in the headwall at that elevation.
SIMPLIFY LAYOUT OF THE COMPLEX REINFORCEMENT
Reinforcing the arch was never going to be easy.

3D modeling allowed us to simplify bar layout as much as possible.

Designers tested schemes to find the best arrangement.

Detailed bar curve radii and arc lengths.

When detailing was done, bar schedule was complete.
Typical rebar in constant arch.

Lower arch bars at 6” spacing are lapped to the footing bars and extend past the optional constr. joint.

Upper arch bars at 12” spacing lap to lower bars.

Upper arch bars oscillate side-to-side to provide stagger between splices.
BD-633M requires lateral #4 ties at 12” max spacing for shear and to tie the two mats together.

Because the arch thickness varies radially, the tie lengths vary, and in the taper segment they vary both radially and longitudinally.

And that is a lot of ties.

WHAT WAS THAT #1 RULE OF 3D DRAFTING AGAIN?
Option A: Provide a detailed shear tie matrix that would show bar marks as they vary radially & longitudinally.

Option B: Use #3 ties at 6” radially, pre-bent with a J-hook on one end, and field bent to 90° at the other.

We chose B...

Contractor went with A.
Spandrel wall reinforced vertically with #5 U-Bars @ 9” top & bottom.

The top of the wall is normal to the front face, but the bottom is at a 55° skew through the arch.

The skew offset through this wall happens to be about 9”.
The top U-bars could have been normal to the top of the wall, the bottom U-bars skewed, and a spiral would have been created for the whole wall.

However, an effective way to present this on 2D drawings wasn’t found.

So all of the bars were skewed except four U-bars in the top corners.
The photos used throughout the presentation were taken by:

- **Tom Knieriem**  
  D-10 Structural Control Engineer

- **Joe Roman**  
  KCI Proj. Manager

- **John Yamashita**  
  NTM Engineer
DETAILING EXAMPLES
The "collar" gives the tapered section a flat surface.

The collar’s perimeter is 90° to the spandrel wall.

The collar is a constant 18” thick from the wall.

The taper enters the collar at an angle from 45°28'00" to 113°11'17".
Counterforts support the spandrel wall against lateral earth pressure.

Small counterforts can be atop the arch, but will create uplift on the arch.

PennDOT’s ARCH software cannot analyze these discreet loads.
Taller counterforts can be anchored to the footings, removing the uplift issue.

To receive the counterfort, a pedestal was created.

The pedestal extends beyond the counterfort to contain the sloped rebar.
Counterfort ends at wall, creating an acute corner which is hard to form & easy to spall.

Reinforcement extends above and beyond headwall.

Could square the top, but issue relocates to the bottom.

Also, the counterfort’s top and sides are no longer at 90°.
Top of counterfort clipped to eliminate form & spall issue.

Reinforcement bent to enter the headwall horizontally.

Front of headwall bumped out to provide development length of counterfort hooks.
Waterproofing membrane should be placed across cold joints under fill.

In this “trough” between the arch ring and the counterfort, we have two cold joints that need to be protected.

That’s 6” wide at the base...

How wide is the carpenter?
While the old detail looked simple in section view, it is very difficult when viewed in 3D.

The better detail fills the bottom of the trough to the weephole invert.

Not only is the "bottom" wider, but it prevents water pooling below the weephole.
The 3D limits of backfill can be used to locate the required limits of the spandrel wall. Clipping the corners reduces excess wall, prevents the erosion concerns of the future inspectors, and is better aesthetically.
The 3D limits of backfill can be used to locate the required limits of the spandrel wall.

Clipping the corners reduces excess wall, prevents the erosion concerns of the inspectors in the future, and is better aesthetically.
CONCLUSION
1. Introduction to Project
2. Alternate Study
3. Constructability & Design-ability
4. Limits of Removal
5. Sequence of Construction
6. Layout of Reinforcement
7. Examples of Detailing