# Bridge Conversion Feasibility Study
# Broadway Street (KY 3506) over Kentucky River
# Franklin County, KY

August 2019

KENTUCKY TRANSPORTATION CABINET

CITY OF FRANKFORT KENTUCKY

In Partnership With

Palmer ENGINEERING

# CONTENTS

# FEASIBILITY STUDY

## BROADWAY BRIDGE OVER KENTUCKY RIVER

FRANKFORT, KY

## 1. HISTORY

Constructed circa 1910, the Broadway Street Bridge has a long history of service to generations of travelers. This Kentucky River crossing has seen several predecessors, reconfigurations, and rehabilitations. In 1851, the Louisville & Frankfort Railroad constructed the first railroad bridge to cross the Kentucky River here. This suspension bridge, believed to have been designed by John A. Roebling, was unable to support the rail loads crossing it, and was soon replaced with a covered bridge in 1856. During the Civil War, the covered bridge was intentionally burned, replaced, and then washed away during a flood.

Construction of an iron Fink truss in 1868 restored the link across the Kentucky River. Around 1910, a new pin-connected Baltimore Petit truss, the current Broadway Street Bridge, replaced the Fink truss bridge. From the beginning, the bridges over the Kentucky River carried railroad traffic. In 1929, the American Bridge Company constructed a railroad truss bridge running parallel and adjacent to the Broadway Bridge (Figure 1).

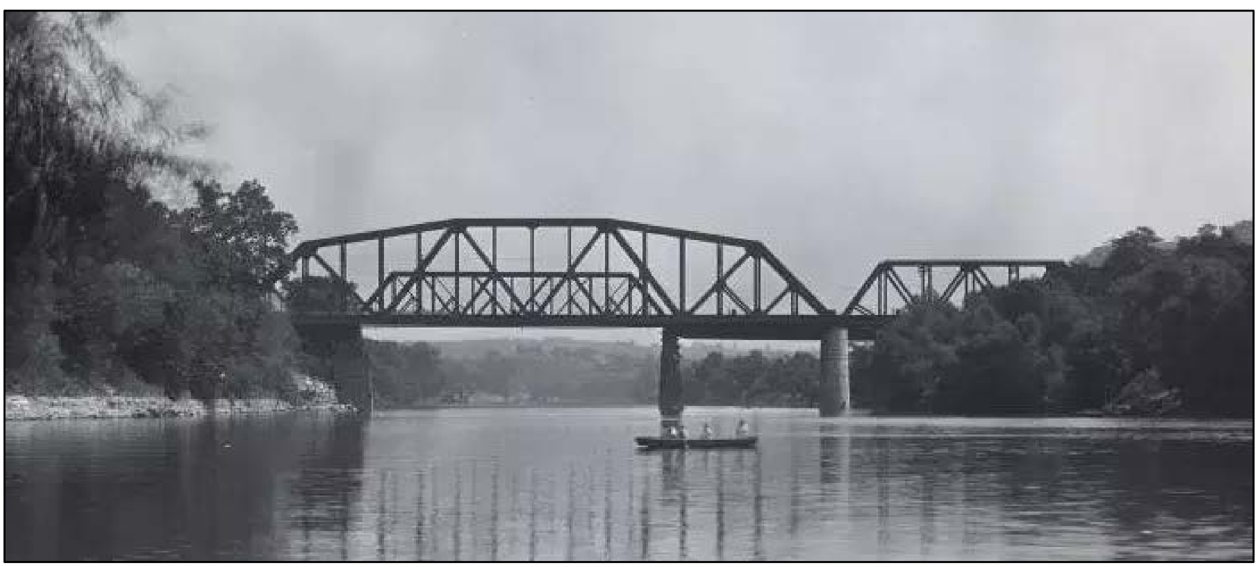


**Figure 1:** Railroad Bridge and Broadway Bridge, circa 1930 by Cusick Studio

A major rehabilitation and reconfiguration in 1951 resulted in the bridge we see today. To better accommodate vehicular use, the trusses and approach girders were disconnected and spread farther apart. Timber roadway, sidewalk and handrails gave way to a new concrete deck and steel handrails. The reconfigured truss included new structural bracing, floorbeams, and stringers. Widened approach spans included floorbeams to carry traffic loads across the wider deck span. Other upgrades included sidewalk brackets to the truss and repairing and recapping piers and abutments.

The bridge carried traffic US 421 and US 127 traffic and in 1977, an inspection found the bridge's floor system to be deteriorated. A subsequent load rating found the bridge to be inadequate for a Class AA truck route, resulting in reduced load limits for the bridge. Due to its reduced load limits, the Broadway Bridge became part of the Substandard Bridge List.

A few years later, in 1982, the Kentucky Transportation Cabinet (KYTC) received notification that the Broadway Bridge was eligible for the National Register of Historic Places. The Register is the United States federal government's official list of places or items deemed worthy of preservation for their historical significance. A 1987 in-depth inspection revealed severe condition issues with stringers, lower truss chords, and some lower chord connections. In 1989, KYTC built new twin bridges over the Kentucky River for the West Frankfort Connector. These new structures began carrying US 421 and US 127 traffic, greatly reducing the amount of traffic crossing the Broadway Bridge.

An underwater bridge inspection found significant problems at Pier 3 in 1990 and recommended closure. The bridge remained open and in 1991, a routine inspection found further deterioration of structural elements causing a further load limit reduction to 3 tons. In December 1993, an in-depth inspection by Burgess & Niple found the overall condition of the bridge to be critical and the bridge was closed to all traffic.

In 1995, Haworth, Meyer, and Boleyn (HMB) prepared a report for the city of Frankfort exploring options for opening the bridge to pedestrian traffic. The report estimated cost of repairs at a bit less than $400,000. However, KYTC anticipated further maintenance and deterioration issues after the proposed repairs, and that additional repairs would be needed at the piers and at sites of severe deterioration. In 2019, the city and state decided to revisit the conversion of the Broadway Bridge for pedestrian use through an in-depth inspection and feasibility study.

## 2. FUTURE VISION

For many years, Frankfort eyed the Broadway Bridge as a possible community asset. Since it closed to vehicular traffic, planners have envisioned using the bridge as another link across the Kentucky River for pedestrians and bicyclists. This wish to bring the bridge back into service is documented in both Frankfort's Downtown Master Plan (2018) and City of Frankfort & Franklin County Pedestrian & Bicycle Master Plan (2016).

The Pedestrian and Bicycle Plan lists replacement of the old bridge as priority 4A: Links that are not as critical but still of interest. The Downtown Master Plan discusses improvements to the pedestrian/bike trail system to make it less fragmented and easier to use. The first recommendation to improve the system is, "Foremost is renovation and reuse of the Broadway Bridge into a pedestrian/bike facility." Figure 2 from Frankfort's Downtown Master Plan shows one idea of how the Broadway Bridge might look if rehabilitated.

**Figure 2:** Broadway Bridge shown in Frankfort Downtown Master Plan

## 3. Existing Conditions

### Inspection

Palmer Engineering performed an in-depth bridge inspection of the Broadway Bridge in June 2019. This type of inspection requires visual inspection of above ground components and requires that inspectors be within an arm's length of all structural elements in order to assess and document their condition.

Broadway Bridge is in a deteriorated condition and has no recent inspection so its structural capacity is unknown. Normally, a snooper-truck on the bridge's deck provides access for inspectors to be within arm's length of the structural members. Due to uncertain structural capacity, this method was not feasible. Instead, Palmer used rope climbing techniques in accordance with SPRAT (Society of Professional Rope Access Technicians), ladders, a boat, and rigging below deck to gain close access.


**Figure 3:** Inspection of pier using rope access in accordance with SPRAT

A pickboard is a movable scaffolding supported by cable rigging. It provided below-deck inspection of the truss and twin girder approach spans as seen in Figure 4.

**Figure 4:** Below-deck inspection of truss from a pickboard

Inspectors used extension ladders from the ground when inspecting the twin girder superstructures of Spans 1, 2, and 6 and for sounding substructure where practical (Figure 5).

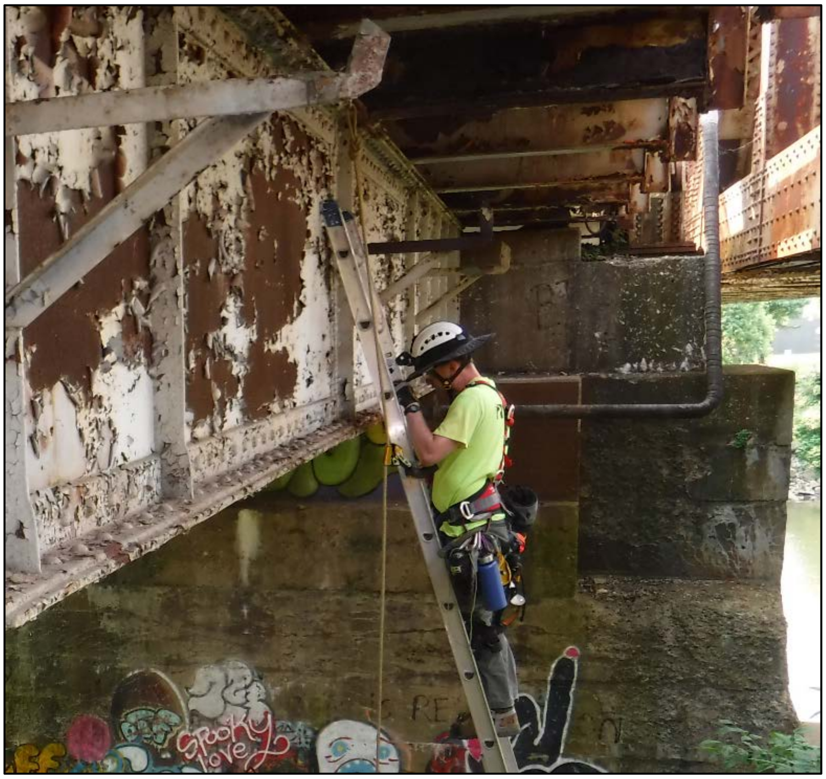


**Figure 5:** Girder inspection from extension ladder

Finally, a manned safety boat provided multiple services for the inspection. It patrolled the water during the in-depth inspection over Kentucky River, ferried inspectors to the river piers so they could sound the masonry, and provided vantage points to take overall bridge and site layout photos for the inspection report.

## CONDITION ASSESSMENT

The in-depth inspection determined that Broadway Bridge is in "imminent" failure condition with a rating of 1 out of 9 according to the Federal Highway Administration's rating guidelines. This condition rating does not necessarily indicate that collapse is likely under current conditions. The rating reflects the major deterioration and section loss on major structural components, as well as the fact that the bridge is currently closed. However, this condition rating also considers that corrective measures may allow the bridge to return to light service. Repairs necessary to return the Broadway Bridge to service are discussed later in this report. A comprehensive discussion of the deterioration found during the inspection is in this report's companion In-Depth Bridge Inspection Report.

## 4. Structural Analysis

The In-Depth Bridge Inspection only examined bridge elements above the ground and water so subsurface structural conditions are unknown. Likewise, river pier stability due to existing conditions and scour potential is unknown. We analyzed the bridge for future pedestrian use and a lightweight service truck; normal highway truck loading is not included.

The bridge superstructure was analyzed in two different programs. The truss was modeled with SAP2000 structural analysis software and load rated for pedestrian loads (90-psf), as well as an H10 truck (20,000-lbs). The girders and floorbeams on the approach spans were modeled along with the truss floorbeams and stringers in LARS (Load Analysis Rating System) Bridge software, and load rated for the same pedestrian loading and H10 truck. Because the bridge was designed using the Allowable Stress Method in the early 1900s, Allowable Stress Rating (ASR) procedures were used in load rating the approach and truss spans. The assumptions used in these analyses as well as the results of the analysis are discussed below.

### Approach Spans

The approach spans consist of twin steel girders spanned by floorbeams, with a reinforced concrete deck. These members were modeled and load rated in LARS Bridge.


**Figure 6:** Approach spans member types

Field measurements were used for determining dimensions of bottom flange plates, angles, and web plates, whereas dimensions noted in repair plans from 1950 were used for top flange plate, lateral bracing, and floorbeam member sizes. Although the Broadway Street Bridge was constructed circa 1910, material properties for steel bridges constructed prior to 1905, based on the AASHTO (American Association of State Highway and Transportation Officials) Manual for Bridge Evaluation, was conservatively used in the analyses.

Load demands were found using continuous beam theory for prismatic sections, and distribution factors for girders and floorbeams were calculated using a tributary width for interior members and simply-supported beam distribution for exterior members. The beam's self-weight was scaled up by a factor of 1.1 to account for splice plates that were not included in the structural model due to deterioration, heavy pack rust, connecting elements, and pipes running along the upstream side of the girders. Lateral bracing loads were averaged and applied as a distributed load along the length of the girders. Section loss was input based on field notes and observations, and only the worst case of deterioration of the two girders within a span was modeled.

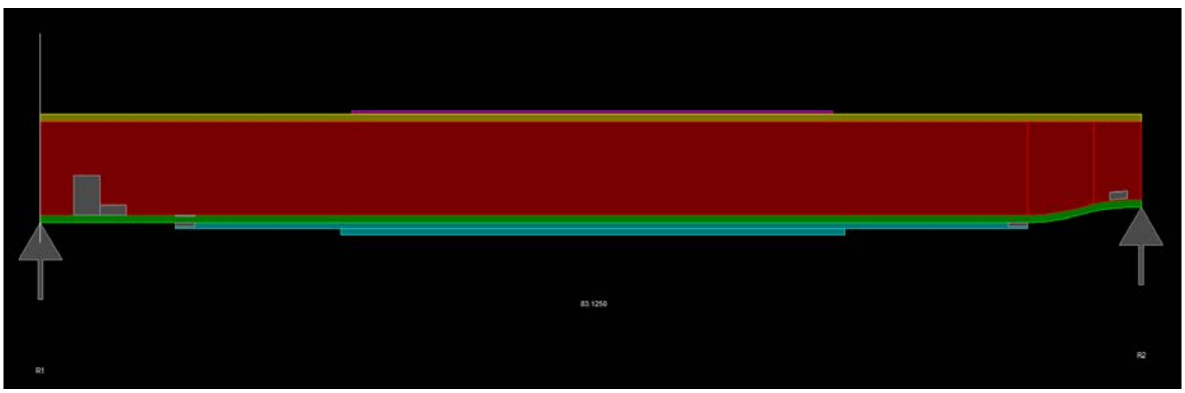


**Figure 7:** Span 4 Steel Girder modeled in LARS Bridge

## TRUSS SPAN

The floorbeams and stringers on the truss span were modeled in LARS Bridge with the same procedure as described above for the approach span's floorbeams and stringers.


**Figure 8:** Truss member types below deck

SAP2000 was used to model the truss itself as a two-dimensional elastic structure.

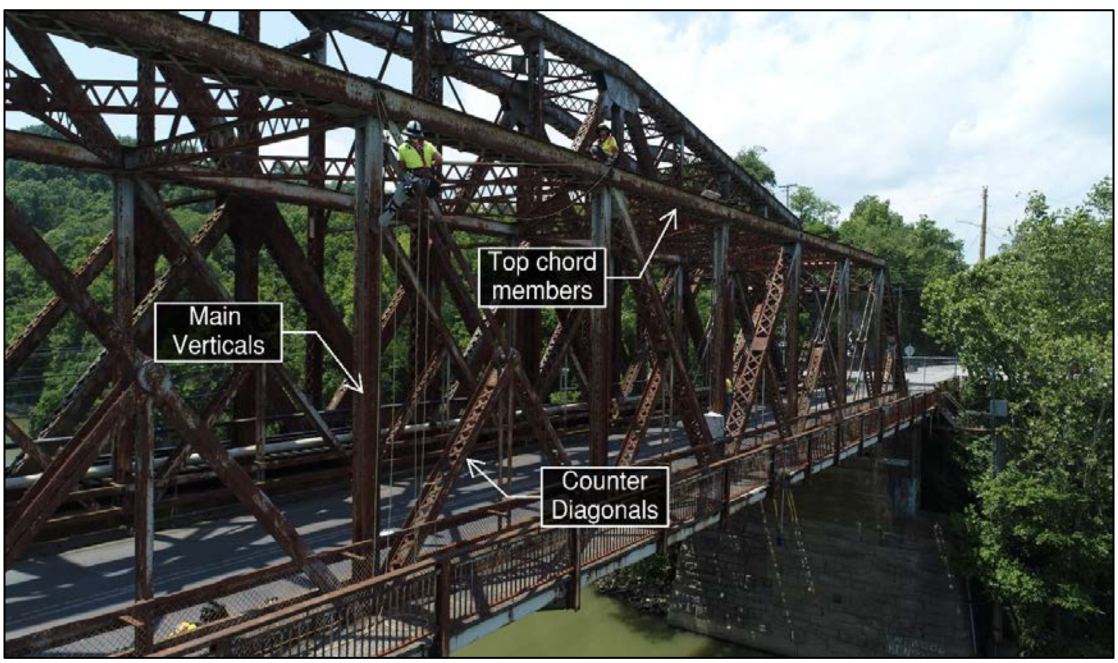



**Figure 9:** Truss member types above deck

Only one trussline was analyzed, using section properties of the more deteriorated of the two. Simply-supported floorbeams between the trusslines allow for quick determination of nodal loads to each of the two truss lines for any patch, strip or off-center loadings.

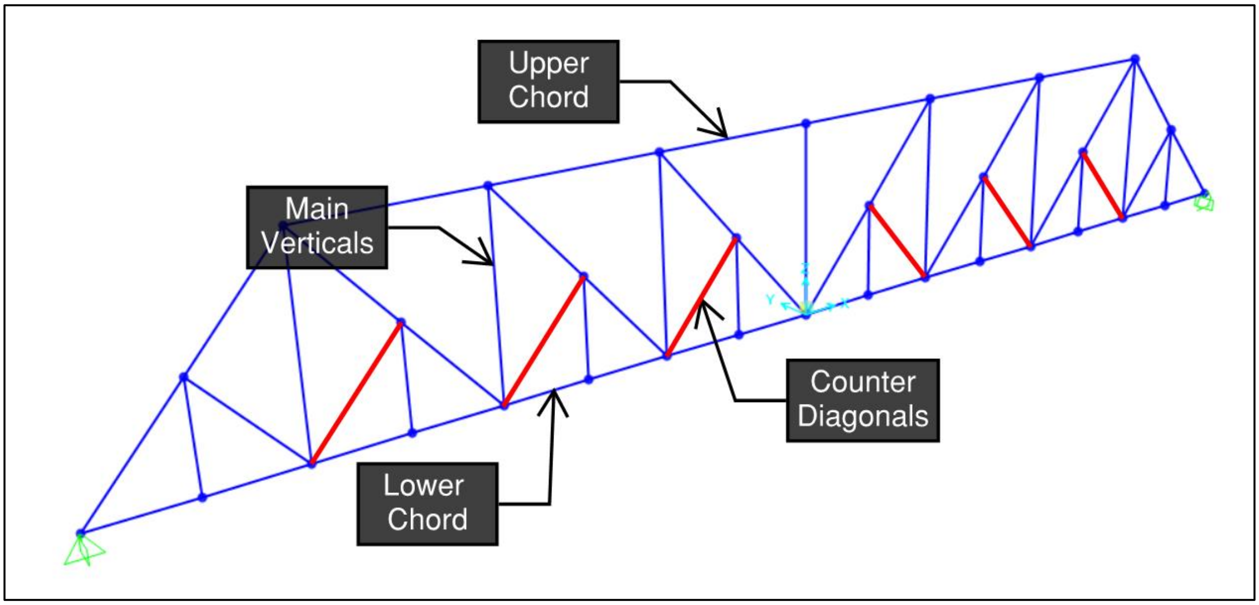



**Figure 10:** Truss Span modeled in SAP2000

The connections between truss members are pin connections, which transfer no moment between members. This is a simplification since, in reality, connections often have enough stiffness to transfer some moment between members, but this load transfer is typically very small and pin connections are accurate for most truss bridges. This assessment uses conventional truss design and behavior with axial-only members and all loads applied to nodes.

Gross cross sectional area for each member were used in the truss model to determine maximum member demands. Broadway Bridge's truss configuration is statically determinant so member stiffness does not affect the distribution of loads in the member. In contrast to determining truss member loads, section loss directly affects member capacity. Each member capacity accounts for any deterioration measured during the inspection.

For modeling moving live loads along the truss, we simply changed the bottom chord members to beam elements, allowing vertical member loading, resulting in the proper vertical load applied to the member end nodes. Lower chord moments from this fictitious moving load are ignored because, in reality, application through floorbeams allow the lower chords to be axial-only members.

For dead loads, we assumed a full-width (23.25 ft.) 8" thick cast-in-place concrete walking path, which is a worst case loading, depending on the type of path surface (i.e. concrete, wood, composite material) and the path width selected. Members with lacing bars had a self-weight modifier of 1.33 applied to account for the addition weight of these lacing bars. All dead loads were applied to the truss model as point loads at nodes.

# 5. Results

## Girder Spans

The twin girders on the approach spans were found to have sufficient capacity to support a full-width (23.25 ft.) 8” thick cast-in-place concrete deck and full pedestrian loading despite some deterioration (top flange cover plates at floorbeams). Span six controlled the load rating for all girders for both pedestrian loading and H10 truck loading, but had rating factors quite a bit larger than the 1.0 minimum required.

Many floorbeams were found to have severe section loss in the approach spans and in the truss span. None of the approach span floorbeams have sufficient section remaining to carry their load demand and all would need to be replaced.

## Truss Span

On the truss span, the five floorbeams located under deck joints are also deficient, and were found to have a rating factor of 0.50 for the H10 truck and would need to be replaced. The other floorbeams in the truss span rated at greater than 1.0 for pedestrian loading and H10 loading.

The stringers in the truss span that are adjacent to any deficient floorbeams will also require replacement. The exterior stringers are also in a deteriorated state, and will need to be removed or replaced, depending on the width of the pedestrian path selected.

The truss analyses led to several conclusions. First, the counter-diagonals present in the middle of each bay were determined to be a major component of truss stability. They have severe section loss, especially at the bottom connection, and are inadequate to carry any live load and, therefore, need to be repaired or replaced.

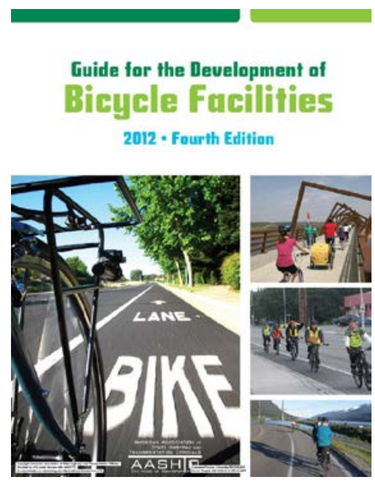
Upper chord members have section loss at splice plate locations. The sufficiency of these members depends on the width and type of pedestrian path selected. For a full-width pedestrian path (23.25 ft. available between truss lines), with an 8” cast-in-place concrete deck, these members have a rating factor of 0.90, and will need to be repaired. However, if a narrower pedestrian path is selected, or one with a wearing surface of a lighter material than concrete (such as wood), these members may not require replacement. In the case of a 12-ft wide pedestrian path with 8” cast-in-place deck, these members are able to support pedestrian and H10 loading in their current condition.

Similarly, the eyebars located near the bearing at the beginning and end of the bridge have a rating factor of 0.77 under full-width concrete deck and pedestrian loading and would require replacement. If a 12 foot-wide pedestrian path with a concrete deck is selected, these members will be satisfactory in their present state.

The analysis also found that many members were sufficient for the full-width multiuse path. The lower chord members were determined to be tension-only members and deterioration of the lacing on them should not decrease their load carrying capacity. Truss members not mentioned above passed a tension and/or compression and buckling check for full-width concrete deck, pedestrian loading, and H10 truck loading. Floorbeam hangers pass tensile fracture and yielding checks despite section loss. Floorbeam connections at main verticals and pins were also calculated to have enough capacity for the full-width concrete deck and live loads.

## 6. Options

### Path Width




The widths considered followed AASHTO's Guide to Bicycle Facilities, 4th Edition. It states:

> *The minimum paved width for a two-directional shared use path is 10 ft. Typically, widths vary from 10 ft to 14 ft, with the wider values applicable to areas with high use and/or a wider variety of user groups.*
>
> *In very rare circumstances, a reduced width of 8 ft may be used.*

### Multiuse Path Options

Repair and reuse of the Broadway Bridge for pedestrian and bicycle use is a viable option. However, several repairs will need to be made to the structure to make it suitable for pedestrian use. The sidewalk and floorbeam overhangs should be removed. The counter diagonals must also be replaced or repaired to return the truss to its original configuration.

The deck must be removed on all spans, and all floorbeams on the approach spans would be replaced. The floorbeams below deck joints on the truss span would also need to be replaced along with the stringers adjacent to them, and the exterior stringers would need to be removed. The deck will then be replaced, and the truss will need to be blast cleaned and painted. The corroded angles and lacing bars on the lower chord members should also be removed, and the holes filled with a tensioned bolt.

A full-width (23.25 ft.) concrete deck pedestrian path requires repairs to some upper chord members, as well as to eyebars at the ends of the truss span near the support. Additionally, this full-width option would require exterior stringers to be replaced, whereas a 12-ft wide concrete deck does not. Therefore, a 23.25 ft. path is not recommended due to both cost of additional repairs and the decreased safety factor inherent in a greater pedestrian design load. A 12-ft wide concrete pedestrian path was analyzed for cost in the following section, since it provides a more cost-effective repair option than a wider path.

Additionally, a 10 ft.-wide wooden path is also an option. This boardwalk-style path has the lowest initial cost, but would require regular maintenance and replacements. It also would probably be pedestrian and bicycle only and might not be able to carry the lightweight service truck that the concrete path can. Other bridges converted into pedestrian use such as Frankfort's Benson Creek Bridge, just to the north of the Broadway Bridge, and the Parsons, WV bridge in Figure 11 are examples of wooden paths.

**Figure 11:** Wooden Pathway on Parsons, WV bridge

## Demolition Options

Two options were studied for partial bridge demolition. The first option is to remove the existing concrete deck. The time and cost of removal is increased due to low load carrying capacity of the bridge in its current condition. A contractor will likely use lightweight equipment on the deck or stage removal equipment beside the bridge on the banks or from barges. Both scenarios result in smaller pieces removed and longer durations. Additionally, working next to an active railroad will increase cost. Likewise, working over water and a navigable waterway increases the cost of work.

The second partial demolition option includes the deck removal discussed above, with further removal of the entire superstructure. All the factors that increase the cost for deck removal also increase the cost of the superstructure removal.

# 7. COST ANALYSIS

## DERIVATION

Based on similar project experience and discussions with Kentucky bridge contractors, the most economical method of deck removal is to remove the deck in pieces working backwards from the center of the bridge to each end or to work backwards from one end of the bridge to the other. Using this approach, the deck is saw cut into slab sections, an excavator lifts the slab sections from the superstructure, places them into a hauling vehicle, and the slabs are transported off the bridge. The severely deteriorated condition of the Broadway Bridge will limit the size of the equipment that can be used on the bridge. It also limits the size and number of slab sections that can be hauled off the bridge at one time. This will increase the time required for the deck removal. Additional time equates to additional cost. The contractor may be forced to remove the deck from below due to equipment restrictions on the bridge. This can double the cost of the deck removal.

The Broadway Bridge location presents two challenges that increase the cost of demolition. The close proximity to the adjacent and active railroad bridge, further complicated by the shared substructure unit (Pier 4), will require railroad approval for the demolition plan. Railroads often require additional safety margins that are over and above standard industry practice for construction and demolition adjacent to their right-of-way. This often results in additional temporary shoring, cranes with larger pick capacities, additional equipment, and additional coordination.

Working above a navigable body of water like the Kentucky River also adds cost. For bridges that cross dry or shallow streams, causeways can be constructed quickly and inexpensively. However, the river width and depth do not accommodate construction of a simple causeway for equipment access. Barges or a more elaborate construction trestle may be required. River navigation will need to remain unimpeded by and protected from construction activities. Coast Guard coordination and approval for demolition activities will be required.

To get the cost estimate for demolition, we used bids from similar projects, adjusted the numbers accordingly based on complexity compared to this project, and then compared the numbers to estimates from Kentucky bridge contractors familiar with this type of demolition work. The cost estimates presented in this report fall within the range of contractor estimates.

To get the cost estimate for repairs and new construction, we used KYTC historic bid prices on similar work, and adjusted the costs accordingly based on complexity and quantity of work. If there were no similar bid items in the KYTC's database, we used prices from ODOT, TDOT, and contractors familiar with the specific type of work to be performed.

Repairs to masonry piers are somewhat rare and unique to a particular site. Finding comparable repair costs to those needed for the Broadway Piers proved challenging. We used available data to estimate repairs that would fully restore the historic integrity. This estimate was quite high so we also included a second pier repair option, namely encasement in a reinforced concrete collar.

## ESTIMATES

Detailed cost estimates are in Appendix A with quantities and unit costs. Table 1 presents a summarized estimate for each option.

**Table 1*:** Cost Estimates

| | Rehab with 12' Concrete Path & Historic Pier Repair | Rehab with 12' Concrete Path & Concrete Pier Repair | Rehab with 10' Wooden Path & Historic Pier Repair | Rehab with 10' Wooden Path & Concrete Pier Repair | New Ped Bridge | Deck Removal | Full Superstructure Removal |
|---|---|---|---|---|---|---|---|
| Deck Removal | $375,000 | $375,000 | $375,000 | $375,000 | $375,000 | $375,000 | |
| Superstructure Removal | | | | | | | $600,000 |
| Truss Rehab | $220,000 | $220,000 | $220,000 | $220,000 | | | |
| Approach Span Rehab | $200,000 | $200,000 | $200,000 | $200,000 | | | |
| Full Historic Pier Repair | $2,366,000 | | $2,366,000 | | | | |
| Pier Repair - Concrete | | $873,000 | | $873,000 | | | |
| 12' Concrete Ped Path | $256,000 | $256,000 | | | | | |
| 10' Timber Ped Path | | | $131,000 | $131,000 | | | |
| Blast Clean & Paint | $487,000 | $487,000 | $487,000 | $487,000 | | | |
| New Ped Bridge | | | | | $1,650,000 | | |
| TOTAL | $3,904,000 | $2,411,000 | $3,779,000 | $2,286,000 | $2,025,000 | $375,000 | $600,000 |

*Rehabilitation Estimates do not include design fees and underwater repairs which are unknown at this time.

## 8. Recommendations

Public safety is of primary concern regardless of the final disposition of Broadway Bridge. Concrete deterioration leads us to recommend wrapping the underside of the bridge with debris netting as soon as practical. River View Park hosts major events and locals enjoy daily access via the pathway underneath the bridge and grassy bank areas. Likewise, boaters enjoy freedom to paddle under spans over the river. To prevent chunks of concrete from falling and injuring someone, debris netting should be installed under all spans. As long as these areas are not protected, deterioration continues, and the likelihood of falling concrete increases. Additionally, access to the bridge deck should continue to be prevented.

If converting the Broadway Bridge to pedestrian use is deemed economically viable, additional investigation is required. Because the in-depth structural inspection was only above ground and water, an underwater inspection is needed to assess the condition of the piers, which have not been inspected underwater recently.

# REFERENCES


1. AASHTO, (2012), *AASHTO Guide to Bicycle Facilities, 4th*, American Association of State Highway and Transportation Officials, Washington D.C.

2. AASHTO, (2017), *AASHTO LRFD Bridge Design Specifications,* 8th Edition with May 2018 Errata, American Association of State Highway and Transportation Officials, Washington D.C.

3. AASHTO, (2018), *The Manual for Bridge Evaluation,* 3rd Edition, American Association of State Highway and Transportation Officials, Washington D.C.

4. Blankenship, A. B. (1977), *Franklin County, MP 37-0421-B0066 Bridge Load Limit Posting,* Kentucky Transportation Cabinet, Frankfort Kentucky.

5. Bogart, Charles H. (2010), *Railroad, Trolley, and Interurban Rail Lines of Frankfort, Kentucky – 175 Years of Rail Service,* Lulu.com

6. *Broadway Bridge (Old US 127 and US 421),* (n.d.), < http://bridgestunnels.com/bridges/ kentucky/ broadway-bridge-old-us-127-old-us-421/>

7. Codell, James C. (1997), *Letter to City of Frankfort*, Kentucky Transportation Cabinet, Frankfort Kentucky.

8. FHWA (1995), *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges*, with February 2018 Errata, Federal Highway Administration, Washington D.C.

9. KYTC (2017), *Kentucky Bridge Inspections Procedures Manual*, Kentucky Transportation Cabinet, Frankfort Kentucky.

10. Poorman, Dale E. (1994), *Letter Regarding In-Depth Inspection Report,* Burgess & Niple, Lexington, Kentucky.

11. Sutherland, Richard K. (1982), *Memorandum on Acceptance to National Register of Historic Places,* Kentucky Transportation Cabinet, Frankfort Kentucky.

12. Sutherland, Richard K. (1994), *Memorandum on Broadway Bridge, Frankfort,* Kentucky Transportation Cabinet, Frankfort Kentucky.

# Appendix A

# Detailed Cost Estimates

**Cost Estimate for**
**Broadway Bridge Feasibility Study**
**City of Frankfort**
**August, 2019**

| ITEM NO. | ITEM | QUANTITY | UNIT | UNIT PRICE | AMOUNT |
|---|---|---|---|---|---|
| 1 | Truss Span Rehabilitation | | | | |
| a | Counter-Diagonal Repair | 16 | EA | $ 7,500.00 | $ 120,000.00 |
| b | Replace Floorbeams and Stringers | 15,500 | LB | $ 3.00 | $ 46,500.00 |
| c | Replace Rivets and Remove Lacing and Angles | 400 | EA | $ 50.00 | $ 20,000.00 |
| d | Repair Lower Chord Lateral Gusset Plates | 10 | EA | $ 2,000.00 | $ 20,000.00 |
| e | Repair Section Loss of Upper Chord Members | 14 | EA | $ 1,000.00 | $ 14,000.00 |
| **1** | **Truss Span Rehabilitation Subtotal** | | | | **$ 220,500.00** |
| 2 | Approach Span Rehabilitation | | | | |
| a | Remove and Replace Floorbeams | 59 | EA | $ 2,400.00 | $ 141,600.00 |
| b | Replace Top Flange Splice Plates | 22 | EA | $ 1,200.00 | $ 26,400.00 |
| c | Remove and Replace Lateral Bracing | 24 | EA | $ 800.00 | $ 19,200.00 |
| d | Remove and Replace X-Frame Members | 7 | EA | $ 1,000.00 | $ 7,000.00 |
| e | Replace Stub-Column Bearings | 2 | EA | $ 3,000.00 | $ 6,000.00 |
| **2** | **Approach Span Rehabilitation Subtotal** | | | | **$ 200,200.00** |
| 3 | Blast Clean and Paint Superstructure | | | | |
| a | Blast Clean and Paint Truss | 24,400 | SF | $ 12.00 | $ 292,800.00 |
| b | Blast Clean and Paint Girders | 19,500 | SF | $ 10.00 | $ 195,000.00 |
| **3** | **Blast Clean and Paint Superstructure Subtotal** | | | | **$ 487,800.00** |
| 4 | Substructure - Full Historic Rehabilitation | | | | |
| a | Abutment 1 | 1 | LS | $ 20,000.00 | $ 20,000.00 |
| b | Pier 2 | 1 | LS | $ - | $ - |
| c | Pier 3 | 1 | LS | $ 750,000.00 | $ 750,000.00 |
| d | Pier 4 | 1 | LS | $ 36,000.00 | $ 36,000.00 |
| e | Pier 5 | 1 | LS | $ 830,000.00 | $ 830,000.00 |
| f | Pier 6 | 1 | LS | $ 620,000.00 | $ 620,000.00 |
| g | Abutment 7 | 1 | LS | $ 110,000.00 | $ 110,000.00 |
| **4** | **Substructure - Full Historic Rehabilitation Subtotal** | | | | **$ 2,366,000.00** |
| 5 | Substructure - Concrete Encasement Repair | | | | |
| a | Abutment 1 | 1 | LS | $ 20,000.00 | $ 20,000.00 |
| b | Pier 2 | 1 | LS | $ - | $ - |
| c | Pier 3 | 1 | LS | $ 150,000.00 | $ 150,000.00 |
| d | Pier 4 | 1 | LS | $ 36,000.00 | $ 36,000.00 |
| e | Pier 5 | 1 | LS | $ 380,000.00 | $ 380,000.00 |
| f | Pier 6 | 1 | LS | $ 250,000.00 | $ 250,000.00 |
| g | Abutment 7 | 1 | LS | $ 37,000.00 | $ 37,000.00 |
| **5** | **Substructure - Concrete Encasement Repair Subtotal** | | | | **$ 873,000.00** |
| 6 | 12' Wide Concrete Deck Pedestrian Path | | | | |
| a | Class AA Concrete | 150 | CUYD | $ 800.00 | $ 120,000.00 |
| b | Steel Reinforcement Epoxy Coated | 26,933 | LB | $ 1.30 | $ 35,012.90 |
| c | Metal Pedestrian Railing | 1,010 | FT | $ 100.00 | $ 101,000.00 |
| **6** | **12' Wide Concrete Deck Pedestrian Path Subtotal** | | | | **$ 256,012.90** |
| 7 | 10' Wide Timber Deck Pedestrian Path | | | | |
| a | Timber Decking | 5,050 | SF | $ 20.00 | $ 101,000.00 |
| b | Timber Pedestrian Railing | 1,010 | FT | $ 30.00 | $ 30,300.00 |
| **7** | **10' Wide Timber Deck Pedestrian Path Subtotal** | | | | **$ 131,300.00** |
| 8 | New Construction 12' Wide Pedestrian Bridge | | | | |
| a | Stand-alone Pedestrian Bridge | 1 | LS | $ 1,650,000.00 | $ 1,650,000.00 |
| **8** | **New Construction 12' Wide Pedestrian Bridge Subtotal** | | | | **$ 1,650,000.00** |
| 9 | Demolition - Concrete Deck | | | | |
| a | Counter-Diagonal Stabilization | 1 | LS | $ 15,000.00 | $ 15,000.00 |
| b | Concrete Deck Removal | 1 | LS | $ 360,000.00 | $ 360,000.00 |
| **9** | **Demolition - Concrete Deck Subtotal** | | | | **$ 375,000.00** |
| 10 | Demolition - Superstructure | | | | |
| a | Superstructure Removal | 1 | LS | $ 600,000.00 | $ 600,000.00 |
| **10** | **Demolition - Superstructure Subtotal** | | | | **$ 600,000.00** |

# Broadway Bridge Feasibility Study

## Repair Quantities and Unit Costs

## 1. Truss Span Rehabilitation

### Counter-Diagonal_Repair:

Counter diagonals have severe section loss near the connection with the lower panel points and heavy section loss at the mid-height panel points. These members are necessary for truss stability.

$N_{st} := 2 \cdot 8 = 16 \ EA$

Use average bids from 2015 Singing Bridge truss member retrofits, and increase slightly.

$$Cost_{CD} := \frac{(6500+8500+8500+8200+8500+5000+5500+8200+5000+5500)}{10} = 6940$$

Use $7,500 per repair

### Replace_Floorbeams_and_Stringers:

Floorbeams and stringers to be replaced include 3~W24X103, 2~W8X31, and 16~W12X35. Cost will be based per lb and applied to the total weight of floorbeams and stringers to be replaced.

Total weight of stringers and floorbeams to be replaced:

$$W_{FBST} := 3 \cdot (25 \cdot ft + 10 \cdot in) \cdot 103 \cdot plf + 2 \cdot (25 \cdot ft + 10 \cdot in) \cdot 31 \cdot plf + 16 \cdot (10.5625 \cdot ft) \cdot 35 \cdot plf = 15499 \ lb$$

Based on past discussions with steel industry representatives, assume rolled shapes can be manufactured and delivered to the site for $1.00 per pound. Double this cost for installation to get an additional $2.00 per pound.

Use $3.00 per pound

### Replace_Rivets_and_Remove_Lacing_and_Angles:

This repair mainly consists of rivet/bolt replacement. Assume there are 400 rivets to remove and replace with bolts.

Highest bid on Cumberland County KY 61 and KY 90 Bridge Repair Project was $51/bolt for replacement. Winning bid on that project was $35/bolt. Since Broadway Bridge project will require lacing bars and angles to be removed and disposed, price used should be close to the highest bid on Cumberland County project.

Use $50 per rivet/bolt

### Repair_Lower_Chord_Lateral_Gusset_Plates:

There are approximately 10 lower chord lateral gusset plates that have heavy section loss and need to be replaced. This should be performed prior to deck removal for lateral stability. This will increase the repair cost.

From TDOT Hancock County TN 70 over Clinch River, lateral bracing repairs were $2100 each. Broadway bridge repairs will be similar, but not as much fabrication will be needed since only the gusset plates need to be replaced.

Use $2,000 each

### Repair_Section_Loss_of_Upper_Chord_Members:

Top chord section loss will be plated over. There are 14 locations to be repaired.

From TDOT Hancock County TN 70 over Clinch River, lower chord splice replacements were $985 each. Broadway bridge repairs will be similar - Easier access but upper chord lateral bracing may need to be removed and reinstalled due to close proximity of repair locations.

Use $1,000 each

## 2. Approach Span Rehabilitation

### Remove_and_Replace_Floorbeams:

All floorbeams on the approach spans will need to be removed and replaced.

$FB_{Span1} := 7$ $\quad FB_{Span2} := 14$ $\quad FB_{Span3} := 15$ $\quad FB_{Span4} := 14$ $\quad FB_{Span6} := 9$

$$Total_{FB} := FB_{Span1} + FB_{Span2} + FB_{Span3} + FB_{Span4} + FB_{Span6} = 59$$

Assume 16' W12x50's used as replacement floorbeams, and $3.00 per pound replacement cost.

$$Cost_{FB} := 16 \cdot 50 \cdot 3 = 2400$$

Use $2,400 each

### Replace_Top_Flange_Splice_Plates:

Assume all top flange splice plates on the girder spans need to be replaced due to severe deterioration encountered during the in-depth inspection.

$$Total_{SP} := 2 \cdot (1 + 3 + 3 + 3 + 1) = 22$$

The cost of this repair will be slightly more expensive than the repair of the upper chord section loss on the truss. Assume 1.2 x upper chord section loss cost.

Use $1,200 each

### Remove_and_Replace_Lateral_Bracing:

The lateral bracing shows signs of corrosoin and pack rust at the connecton plates. Not all of them will need to be replaced based on inspection. Assume 50% replacement of the lateral bracing.

Lateral Bracing: 4 x 3.5 x 3/8" Angle 15.5' long    48 memebrs

Top Plate: 20" x 14" x 3/8" plate    53 plates

Lateral Bracing Steel Weight: $LB := 48 \cdot 15.5 \cdot 9.10 = 6770.4$ *lbs*

Top Plate Weight: $Plate := 53 \cdot 20 \cdot 14 \cdot 15.3 \cdot \frac{1}{144} = 1576.75$ *lbs*

$Total_{LB} := (LB + Plate) \cdot 0.50 = 4173.575$ *lbs*

Assume $3.00/lb for steel + $250 per member for removal.

$$Cost_{LB} := \frac{Total_{LB} \cdot 3.00 + 250 \cdot 48 \cdot 0.5}{24} = 771.6969 \text{ dollars}$$

Use $800 each

## Remove_and_Replace_X-Frame_Members:

The cross-frames show the same corrosion and pack rust at the top flange connections, but the remainder of the cross frame assembly is in satisfactory condition. Assume 25% replacemnt of the top member of the x-frames.

X-Frame Top Member: 4 x 3 x 3/8" Angle 13.5' long    28 members

Top Member Weight: $XF := 28 \cdot 8.5 \cdot 13.5 = 3213$ *lbs*

$Total_{XF} := XF \cdot 0.25 = 803.25$ *lbs*

Try $3.00/lb for steel + $250 per member for removal, similar to Lateral Bracing.

$$Cost_{XF} := \frac{Total_{XF} \cdot 3.00 + 28 \cdot 0.25 \cdot 250}{7} = 594.25 \text{ dollars (too low)}$$

Due to small quantity and low steel weight each, the above equation does not adequately capture anticipated cost of removal and replacement. Use a slight premium to the cost for the lateral bracing replacement.

Use $1,000 each

## Replace_Stub-Column_Bearings:

Both stub-column bearings of Span 1 at Pier 2 need to be replaced. Other bearings are rusted and potentially frozen, but due to relatively short span length and in an effort to keep cost as low as practical, only replace the 2 stub-column bearings.

Palmer Engineering I-65 Bridges Planning Study for KYTC estimated $2,000 per bearing replacement. Since there are only 2 bearings to be replaced, and they are more complex than a typical bearing replacement, use 1.5 x planning study estimate.

Use $3,000 each

# 3. Blast Clean and Paint Superstructure

## Blast_Clean_and_Paint_Truss:

Determine the total surface area of members on the truss.

Stringers

Stringers are 12WF36.

$$L_{st} := 16 \cdot 4 \cdot (10 \cdot ft + 6.75 \cdot in) = 676\ ft$$

Use dimensions of W12X35 to estimate surface area or stringers.

$$SA_{st} := 2 \cdot 12.5 \cdot in + 4 \cdot 6.56 \cdot in = 4.27\ \frac{ft^2}{ft}$$

$$A_{st} := L_{st} \cdot SA_{st} = 2886.52\ ft^2$$

Floorbeams

Floorbeams that will remain are 24WF100, use W24X103 to estimate surface area

$$L_{fb24w} := 15 \cdot (25 \cdot ft + 10 \cdot in) = 387.5\ ft$$

$$SA_{fb24w} := 2 \cdot 24.5 \cdot in + 4 \cdot 12 \cdot in = 8.08\ \frac{ft^2}{ft}$$

$$L_{fb8w} := 2 \cdot (25 \cdot ft + 10 \cdot in) = 51.67\ ft$$

$$SA_{fb8w} := 2 \cdot 8 \cdot in + 4 \cdot 8 \cdot in = 4\ \frac{ft^2}{ft}$$

$$A_{fb} := L_{fb24w} \cdot SA_{fb24w} + L_{fb8w} \cdot SA_{fb8w} = 3338.96\ ft^2$$

Lower_Chord_Lateral_Bracing

Lower chord lateral bracing members are 4x3.5x.375 angles.

$$L_{lclb} := 32 \cdot \left((10.5625 \cdot ft)^2 + (12.042 \cdot ft)^2\right)^{0.5} = 512.58\ ft$$

$$SA_{lclb} := ((4 + .375 \cdot 2 + 3.5) \cdot 2 \cdot in) = 1.38\ \frac{ft^2}{ft}$$

$$A_{lclb} := L_{lclb} \cdot SA_{lclb} = 704.79\ ft^2$$

Lower_Chord_Eyebars

Assume all eyebars are 6.5x1.75 (envelope of all sizes)

$$L_{lceb} := 169 \cdot ft \cdot 4 + (21 \cdot ft + 1.5 \cdot in) \cdot 2 \cdot 4 = 845\ ft$$

$$SA_{lceb} := 6.5 \cdot in \cdot 2 + 1.75 \cdot in \cdot 2 = 1.38\ \frac{ft^2}{ft}$$

$$A_{lceb} := L_{lceb} \cdot SA_{lceb} = 1161.88\ ft^2$$

Main_Diagonal_Eyebars

$$L_{mdeb} := \left((25 \cdot ft)^2 + (21 \cdot ft + 1.5 \cdot in)^2\right)^{.5} \cdot 4 \cdot 2 = 261.84 \ ft$$

$$SA_{mdeb} := 6 \cdot in \cdot 2 + 1.5 \cdot in \cdot 2 + 6 \cdot in \cdot 2 + 1.5 \cdot in \cdot 2 = 2.5 \ \frac{ft^2}{ft}$$

$$A_{mdeb} := L_{mdeb} \cdot SA_{mdeb} = 654.6 \ ft^2$$

Vertical_Eyebars

$$L_{veb} := 12.5 \cdot ft \cdot 8 \cdot 4 = 400 \ ft$$

$$SA_{veb} := 4 \cdot in \cdot 2 + .75 \cdot in \cdot 2 = 0.79 \ \frac{ft^2}{ft}$$

$$A_{veb} := L_{veb} \cdot SA_{veb} = 316.67 \ ft^2$$

Main_Z-Verticals

$$L_{zv} := 25 \cdot ft \cdot 7 \cdot 2 = 350 \ ft$$

$$SA_{zv} := 10.625 \cdot in \cdot 2 + 12.75 \cdot in \cdot 2 + 4 \cdot 2.875 \cdot in \cdot 4 + 5 \cdot in \cdot 4 = 9.4 \ \frac{ft^2}{ft}$$

$$A_{zv} := L_{zv} \cdot SA_{zv} = 3288.54 \ ft^2$$

610_Diagonals

This calculation assumes the lacing bars are actually solid plates, and is conservative.

$$L_{610} := \frac{L_{mdeb}}{2} = 130.92 \ ft$$

$$SA_{610} := 12.25 \cdot in \cdot 4 + 21.5 \cdot in \cdot 4 + 2.5 \cdot in \cdot 4 = 12.08 \ \frac{ft^2}{ft}$$

$$A_{610} := L_{610} \cdot SA_{610} = 1581.96 \ ft^2$$

Counter_Diagonals

$$L_{cd} := \left((12.5 \cdot ft)^2 + (10 \cdot ft + 7.65 \cdot in)^2\right)^{.5} \cdot 8 \cdot 2 = 262.62 \ ft$$

This calculation assumes the lacing bars are actually solid plates, and is conservative.

$$SA_{cd} := 8.5 \cdot in \cdot 4 + 15.5 \cdot in \cdot 4 = 8 \ \frac{ft^2}{ft}$$

$$A_{cd} := L_{cd} \cdot SA_{cd} = 2100.94 \ ft^2$$

Upper_Chord_Built-up_Members

This calculation assumes the lacing bars are actually solid plates, and is conservative.

$$L_{uc} := \left((25 \cdot ft)^2 + (21 \cdot ft + 1.5 \cdot in)^2\right)^{.5} \cdot 2 \cdot 2 + 6 \cdot 2 \cdot (21 \cdot ft + 1.5 \cdot in) = 384.42 \ ft$$

$$SA_{uc} := 25 \cdot in \cdot 2 + 19 \cdot in \cdot 4 + 2.63 \cdot in \cdot 4 = 11.38 \ \frac{ft^2}{ft}$$

$A_{uc} := L_{uc} \cdot SA_{uc} = 4373.43\ ft^2$

Upper_Chord_Lateral_Bracing

From dead load calculations use weight of upper chord bracing to back out a surface area.

$W := 1.37 \cdot kp \cdot 5 + 1 \cdot kp \cdot 2 = 8.85\ kp$

$V := \dfrac{W}{490 \cdot pcf} = 18.06\ ft^3$

Lacing bar and angle thickness is 5/16"

$A_{uclb} := \dfrac{V}{\dfrac{5}{16} \cdot in} \cdot 2 = 1387.1\ ft^2$

Portal_Bracing

From dead load calculations use weight of portal bracing to back out a surface area.

$W := 1.42 \cdot kp \cdot 2 = 2.84\ kp$

$V := \dfrac{W}{490 \cdot pcf} = 5.7959\ ft^3$

Lacing bar and angle thickness is 3/8"

$A_{pb} := \dfrac{V}{\dfrac{3}{8} \cdot in} \cdot 2 = 370.9388\ ft^2$

Total_Area_of_Truss_Members_to_Paint

Increase total by 10% for miscellaneous steel and connections.

$$\boxed{A_{tot} := \left(A_{uclb} + A_{pb} + A_{uc} + A_{cd} + A_{610} + A_{zv} + A_{veb} + A_{mdeb} + A_{lceb} + A_{lclb} + A_{fb} + A_{st}\right) \cdot 1.1 = 24382.96\ ft^2}$$

Use 24,400 SF

Based on KYTC Division of Maintenance correspondence and TDOT historic prices, use $12 per SF for the truss since slightly more complicated than girders.

## Blast_Clean_and_Paint_Girders:

Ignore stiffeners, splices, and rivet heads when determining surface areas of members. Numbers rounded up at the end and conservative dimensions used. For girders use the flange thickness at midspan and consider it uniform over the entire span. To get total height of girders use LARS file. Also conservatively ignore the the haunched portion at the end of Span 4 (use max. depth). Ignore connection plates and gusset plates.

Span 1:

Floorbeams:

Proposed Lengths of Floorbeams: $L_{FB} := 16\ ft$

Perimeter of FBs: $P_{W12x40} := 2 \cdot (2 \cdot 8\ in + 12\ in - 0.295\ in) = 55.41\ in$

$P_{W12x53} := 2 \cdot (2 \cdot 10\ in + 12.1\ in - 0.345\ in) = 63.51\ in$

$S_{1FB} := 6 \cdot P_{W12x40} \cdot L_{FB} + P_{W12x53} \cdot L_{FB} = 527.96\ ft^2$

Diaphragms:
(4)

L4x3x3/8 $P_{4x3x0.375} := 4\ in \cdot 2 + 3\ in \cdot 2 = 14\ in$

L3x3x3/8 $P_{3x3x0.375} := 12\ in$

$L_{4x3x0.375} := 14\ ft \cdot 2 = 28\ ft$

$L_{3x3x0.375} := 4 \cdot \sqrt{7^2 + 4.375^2}\ ft + 4.375\ ft = 37.3939\ ft$

$S_{1dia} := 4 \cdot \left(P_{4x3x0.375} \cdot L_{4x3x0.375} + P_{3x3x0.375} \cdot L_{3x3x0.375}\right) = 280.2424\ ft^2$

Lateral Bracing: $L_{LB} := 6 \cdot \sqrt{(6\ ft)^2 + (14\ ft)^2} = 91.3893\ ft$

$P_{4x3x0.375} = 14\ in$

$S_{1LB} := L_{LB} \cdot P_{4x3x0.375} = 106.6208\ ft^2$

Girders: $L_{Gs1} := 37.75\ ft \cdot 2 = 75.5\ ft$

$P_{Gs1} := 2 \cdot \left(2 \cdot 12\ in + 53.125\ in - \frac{3}{8}\ in\right) = 153.5\ in$

$S_{1G} := L_{Gs1} \cdot P_{Gs1} = 965.7708\ ft^2$

Total Paint Span 1: $\boxed{S_1 := S_{1FB} + S_{1dia} + S_{1LB} + S_{1G} = 1880.5941\ ft^2}$

Span 2:

Floorbeams:

Proposed Lengths of Floorbeams: $L_{FB} := 16\ ft$

Perimeter of FBs: $P_{W12x40} := 2 \cdot (2 \cdot 8\ in + 12\ in - 0.295\ in) = 55.41\ in$

$P_{W12x53} := 2 \cdot (2 \cdot 10\ in + 12.1\ in - 0.345\ in) = 63.51\ in$

$S_{2FB} := 12 \cdot P_{W12x40} \cdot L_{FB} + 2 \cdot P_{W12x53} \cdot L_{FB} = 1055.92\ ft^2$

Diaphragms:
(7)

L4x3.5x3/8 $P_{4x3.5x0.375} := 4\ in \cdot 2 + 3.5\ in \cdot 2 = 15\ in$

L3.5x3x3/8 $P_{3.5x3x0.375} := 13\ in$

$L_{4x3.5x0.375} := 14\ \text{ft} \cdot 2 = 28\ \text{ft}$

$L_{3.5x3x0.375} := 4 \cdot \sqrt{7^2 + 6.375^2}\ \text{ft} + 6.375\ \text{ft} = 44.2465\ \text{ft}$

$S_{2dia} := 7 \cdot \left(P_{4x3.5x0.375} \cdot L_{4x3.5x0.375} + P_{3.5x3x0.375} \cdot L_{3.5x3x0.375}\right) = 580.5359\ \text{ft}^2$

Lateral Bracing: $L_{LB} := 12 \cdot \sqrt{(7\ \text{ft})^2 + (14\ \text{ft})^2} = 187.8297\ \text{ft}$

$P_{5x3.5x0.4375} := 17\ \text{in}$

$S_{2LB} := L_{LB} \cdot P_{5x3.5x0.4375} = 266.0921\ \text{ft}^2$

Girders: $L_{Gs2} := 85.583\ \text{ft} \cdot 2 = 171.166\ \text{ft}$

$P_{Gs2} := 2 \cdot \left(2 \cdot 12\ \text{in} + 87.4375\ \text{in} - \frac{1}{2}\ \text{in}\right) = 221.875\ \text{in}$

$S_{2G} := L_{Gs2} \cdot P_{Gs2} = 3164.788\ \text{ft}^2$

Total Paint Span 2: $\boxed{S_2 := S_{2FB} + S_{2dia} + S_{2LB} + S_{2G} = 5067.336\ \text{ft}^2}$

Span 3:

Floorbeams:

Proposed Lengths of Floorbeams: $L_{FB} := 16\ \text{ft}$

Perimeter of FBs: $P_{W12x40} := 2 \cdot (2 \cdot 8\ \text{in} + 12\ \text{in} - 0.295\ \text{in}) = 55.41\ \text{in}$

$P_{W12x53} := 2 \cdot (2 \cdot 10\ \text{in} + 12.1\ \text{in} - 0.345\ \text{in}) = 63.51\ \text{in}$

$S_{3FB} := 12 \cdot P_{W12x40} \cdot L_{FB} + 2 \cdot P_{W12x53} \cdot L_{FB} = 1055.92\ \text{ft}^2$

Diaphragms:
(7)

L4x3.5x3/8 $P_{4x3.5x0.375} := 4\ \text{in} \cdot 2 + 3.5\ \text{in} \cdot 2 = 15\ \text{in}$

L3.5x3x3/8 $P_{3.5x3x0.375} := 13\ \text{in}$

$L_{4x3.5x0.375} := 14\ \text{ft} \cdot 2 = 28\ \text{ft}$

$L_{3.5x3x0.375} := 4 \cdot \sqrt{7^2 + 6.375^2}\ \text{ft} + 6.375\ \text{ft} = 44.2465\ \text{ft}$

$S_{3dia} := 7 \cdot \left(P_{4x3.5x0.375} \cdot L_{4x3.5x0.375} + P_{3.5x3x0.375} \cdot L_{3.5x3x0.375}\right) = 580.5359\ \text{ft}^2$

Lateral Bracing: $L_{LB} := 12 \cdot \sqrt{(7\ ft)^2 + (14\ ft)^2} = 187.8297\ ft$

$P_{5x3.5x0.4375} := 17\ in$

$S_{3LB} := L_{LB} \cdot P_{5x3.5x0.4375} = 266.0921\ ft^2$

Girders: $L_{Gs3} := 84.667\ ft \cdot 2 = 169.334\ ft$

$P_{Gs3} := 2 \cdot \left(2 \cdot 12\ in + 87.8088\ in - \frac{1}{2}\ in\right) = 222.6176\ in$

$S_{3G} := L_{Gs3} \cdot P_{Gs3} = 3141.3941\ ft^2$

Total Paint Span 3: $\boxed{S_3 := S_{3FB} + S_{3dia} + S_{3LB} + S_{3G} = 5043.9421\ ft^2}$

Span 4: Span 4 is almost the same length as span 2 since we are ignoring the haunch for conservativeness, but has one extra floorbeam:

$\boxed{S_4 := S_2 + P_{W12x40} \cdot L_{FB} = 5141.216\ ft^2}$

Span 6:

Floorbeams:

Proposed Lengths of Floorbeams: $L_{FB} := 16\ ft$

Perimeter of FBs: $P_{W12x40} := 2 \cdot (2 \cdot 8\ in + 12\ in - 0.295\ in) = 55.41\ in$

$P_{W12x53} := 2 \cdot (2 \cdot 10\ in + 12.1\ in - 0.345\ in) = 63.51\ in$

$S_{6FB} := 8 \cdot P_{W12x40} \cdot L_{FB} + P_{W12x53} \cdot L_{FB} = 675.72\ ft^2$

Diaphragms:

(4)

L4x3x3/8 $P_{4x3x0.375} := 4\ in \cdot 2 + 3\ in \cdot 2 = 14\ in$

L3x3x3/8 $P_{3x3x0.375} := 12\ in$

$L_{4x3x0.375} := 14\ ft \cdot 2 = 28\ ft$

$L_{3x3x0.375} := 4 \cdot \sqrt{7^2 + 4.375^2}\ ft + 4.375\ ft = 37.3939\ ft$

$S_{6dia} := 4 \cdot \left(P_{4x3x0.375} \cdot L_{4x3x0.375} + P_{3x3x0.375} \cdot L_{3x3x0.375}\right) = 280.2424\ ft^2$

Lateral Bracing: $L_{LB} := 6 \cdot \sqrt{(7.5\ ft)^2 + (14\ ft)^2} = 95.2943\ ft$

$P_{4x3x0.375} = 14\ in$

$S_{6LB} := L_{LB} \cdot P_{4x3x0.375} = 111.1767\ ft^2$

Girders: $L_{Gs6} := 48.583\ ft \cdot 2 = 97.166\ ft$

$$P_{Gs6} := 2 \cdot \left(2 \cdot 12\ \text{in} + 53.5625\ \text{in} - \frac{3}{8}\ \text{in}\right) = 154.375\ \text{in}$$

$$S_{6G} := L_{Gs6} \cdot P_{Gs6} = 1250.0001\ \text{ft}^2$$

Total Paint Span 6: $\boxed{S_6 := S_{6FB} + S_{6dia} + S_{6LB} + S_{6G} = 2317.1392\ \text{ft}^2}$

Total_Area_of_Truss_Members_to_Paint

$$\boxed{Paint := 1.0 \cdot \left(S_1 + S_2 + S_3 + S_4 + S_6\right) = 19450.2273\ \text{ft}^2}$$

Use 19,500 SF

Based on KYTC Division of Maintenance correspondence and TDOT historic prices, use $10 per SF for the girders since slightly less complicated than truss.

# 4. Substructure-Full Historic Rehabilitation

The Plans from the repair plans (1950s) did not have size dimensions for the area of masonry blocks, however did give the cap dimensions. Our method of determining masonry was based off the pictures we took in the field, then printing them to PDF Using the measuring tool on PDF and the known cap dimensions we were able to encapsulate the areas relatively accurately. This quantity does not include the underwater section of the pier.

Determine the amount of repairs for each pier. Assume at a minimum that all masonry faces will have the joints repointed, Repoint Stone Masonry $65/SF. Heavy map cracking of the stone or significant deterioration and spalling will be repaired with Stone Masonry Reconstruction $800/SF. Any other cracking in the stone will be repaired with Masonry Crack Repair $150/LF.

Cost of Repoint Stone Masonry comes from ODOT similar projects with an average bid of $65 per SF. KYTC Cherokee Park Bridge Project winning bid for repointing masonry was $20 per LF. Assuming 3 LF mortar per SF of wall, this bid price equates to $60 per SF. Therefore, use $65 per SF.

Cost of Stone Masonry Reconstruction comes from ODOT similar projects with an average bid of $1,000 per SF. KYTC Cherokee Park Bridge Project winning bid for Stone Masonry Veneer (closest bid item) was $628 per SF. Split the difference between these two numbers and use $800 per SF.

Winning bid for Masonry Crack Repair on KYTC Cherokee Park Bridge Project was $100 per LF. This is less than the $107 per LF estimate from the I-65 Bridges Planning Study for concrete epoxy injection. Due to the complications associated with old masonry, we anticipate a higher price for the Broadway Bridge. Use $150 per LF.

The cost for concrete repairs are from the 2019 I-65 Bridges Planning Study. Concrete Patching Repair $147/sqft and Concrete Epoxy Injection $107/LF.

Area of a Trapezoid: a= Base (top)

b= Base (bot)

h=Height

$$A := \frac{(a + b)}{2} \cdot h$$

# Abutment_1:

There are popouts and scaling thoughout the abutment surface, assume 90sqft of patching.
Spalling with exposed rebar of the backwall, 10sqft.
Crack repairs, 50ft.

Concrete Patching: $CP_{A1} := 90\ ft^2 + 10\ ft^2 = 100.00\ ft^2$

Epoxy Injection $EI_{A1} := 50\ ft$

Repair Cost: $Cost_{A1} := CP_{A1} \cdot \frac{147}{ft^2} + EI_{A1} \cdot \frac{107}{ft} = 20050$

Use $20,000 LS

# Pier_2:

No repairs needed

# Pier_3:

$$SA_{EF} := (25\ ft) \cdot 8.88\ ft = 222\ ft^2$$

$$SA_{WF} := (25\ ft) \cdot (19.5\ ft) = 487.5\ ft^2$$

North and south face doesnt have a good straight on pic so estimate from plans that pier point is 4ft x 4ft. Use an average of the EF and WF Heights. Assume 4.5ft by 4.5ft triangle at base.

$$SA_{END} := 2 \cdot \left( \frac{\sqrt{2 \cdot 4^2}\ ft + \sqrt{2 \cdot 4.5^2}\ ft}{2} \right) \cdot \left( \frac{8.88\ ft + 19.5\ ft}{2} \right) = 170.6\ ft^2$$

Pier 3 Total Surface Area: $\boxed{P_3 := SA_{EF} + SA_{WF} + 2 \cdot SA_{END} = 1050.7\ ft^2}$

Repairs to Pier 3:

Only good section of stone on Pier 3 is on the west face under the bearings.
This will be repointed and the rest of the pier will have to be reconstructed.
Add 20LF of crack repair for cracks that could have been missed.
Repair the concrete cap on top of the stone, 73 sqft. The ditch in the cap is 3ft wide by 8ft long, 24 sqft.

Repoint: $RP_{P3} := 17.6\ ft \cdot 8\ ft = 140.8\ ft^2$

Reconstruct: $RC_{P3} := P_3 - RP_{P3} = 909.9\ ft^2$

Crack Repair: $CR_{P3} := 20\ ft$

Concrete Patching: $CP_{P3} := 73\ ft^2 + 24\ ft^2 = 97\ ft^2$

Epoxy Injection $EI_{P3} := 0\ ft$

Pier 3 Repair Cost:

$$Cost_{P3} := RP_{P3} \cdot \frac{65}{ft^2} + RC_{P3} \cdot \frac{800}{ft^2} + CR_{P3} \cdot \frac{150}{ft} + CP_{P3} \cdot \frac{147}{ft^2} + EI_{P3} \cdot \frac{107}{ft} = 754292$$

Use $750,000 LS

## Pier_4:

Repair the heavy efflorescencse with concrete patching and the other cracks with epoxy injection. There are no major spalls. Neglect deterioration under adjacent railroad bridge.
East face - 4ft by 10ft.
West face - 8ft by 8ft and 4ft by 4ft.
North face - 4ft by 4ft.
Crack repair - 150ft

Concrete Patching: $CP_{P4} := (4 \cdot 10 + 8 \cdot 8 + 4 \cdot 4 + 4 \cdot 4)\ ft^2 = 136\ ft^2$

Epoxy Injection $EI_{P4} := 150\ ft$

Pier 4 Repair Cost:

$$Cost_{P4} := CP_{P4} \cdot \frac{147}{ft^2} + EI_{P4} \cdot \frac{107}{ft} = 36042$$

Use $36,000 LS

## Pier_5:

$$SA_{EF} := \frac{(25.5\ ft + 38.5\ ft)}{2} \cdot 31.5\ ft = 1008\ ft^2$$

Assume the end point is at a 45 degree angle. At the top the width is 8ft and 14.ft at the base. Use half of these widths for the legs of the triangle.

$$SA_{END} := 2 \cdot \left( \frac{\sqrt{2 \cdot 4^2}\ ft + \sqrt{2 \cdot 7^2}\ ft}{2} \right) \cdot (31.4\ ft) = 488.5\ ft^2$$

Pier 5 Total Surface Area: $\boxed{P_5 := SA_{EF} \cdot 2 + SA_{END} \cdot 2 = 2992.9\ ft^2}$

Repairs to Pier 5:

The east face has 3 full height cracks and the bottom 2 rows of stone need to be reconstructed.
West face 3 full height cracks and the bottom 3 rows of stone need to be reconstructed.
North face has 1 full height cracks and the bottom 3 rows of stone need to be reconstructed.
South face has 2 full height cracks and the bottom 2 rows of stone need to be reconstructed.
The entire concrete cap was replaced when the bridge was reconfigured so there are only minor concrete repairs. Assume 10sft patching and 20ft of crack repairs.

Reconstruct: $RC_{P5} := 38.5\ ft \cdot (6+8)\ ft + 2 \cdot 7\ ft \cdot \sqrt{2} \cdot (8+6)\ ft = 816.2\ ft^2$

Crack Repair: $CR_{P5} := (3+3+1+2) \cdot (31.5-7)\ ft = 220.5\ ft$

Repoint: $RP_{P5} := P_5 - RC_{P5} = 2176.8\ ft^2$

Concrete Patching: $CP_{P5} := 10\ ft^2 = 10\ ft^2$

Epoxy Injection $EI_{P5} := 20\ ft$

Pier 5 Repair Cost:

$$Cost_{P5} := RP_{P5} \cdot \frac{65}{ft^2} + RC_{P5} \cdot \frac{800}{ft^2} + CR_{P5} \cdot \frac{150}{ft} + CP_{P5} \cdot \frac{147}{ft^2} + EI_{P5} \cdot \frac{107}{ft} = 831123$$

Use $830,000 LS

## Pier_6:

Due to the picture taken at the water level and looking up the width at the base of the pier is inflated so use 60ft wide at the base.

$$SA_{EF} := \frac{(51\ ft + 60\ ft)}{2} \cdot 27\ ft = 1498.5\ ft^2$$

Use an average width of 53ft for the WF and estimate the height at each end and the middle.

$$SA_{WF} := 53\ ft \cdot \left(\frac{10\ ft + 6\ ft + 12\ ft}{3}\right) = 494.7\ ft^2$$

From the plans the pier is 13'-2" wide at the cap and the pictures show that at about 10ft above the water line the pier widens to about 16ft. Assume both faces are the same.

$$SA_{END} := 13.17\ ft \cdot (27\ ft - 10\ ft) + 16\ ft \cdot 10\ ft = 383.9\ ft^2$$

Pier 6 Total Surface Area: $\boxed{P_6 := SA_{EF} + SA_{WF} + SA_{END} \cdot 2 = 2760.9\ ft^2}$

Repairs to Pier 6:

The east face has 9 full height cracks and 20sqft of stone to be reconstructed.
In the lower north section of the east face near the graffiti.
The middle 2/3 of the west face needs to me reconstructed. Add 20LF for cracking.
The ends appear to be in good shape, but add 3 full height cracks to be consistent with the east and west face.
The east face concrete has heavy deterioration, repair half the face 32ft by 8ft.
The west face concrete has heavy deterioration, repair all the face 32ft by 16ft.
Assume half the side faces need cocnrete reapir, 9ft by 16ft.
Assume 50ft crack repair.

Reconstruct: $RC_{P6} := 20\ ft^2 + \frac{2}{3} \cdot SA_{WF} = 349.8\ ft^2$

Crack Repair: $CR_{P6} := (9+3) \cdot 27\ ft = 324\ ft$

Repoint: $RP_{P6} := P_6 - RC_{P6} = 2411.2\ ft^2$

Concrete Patching: $CP_{P6} := (32 \cdot 8 + 32 \cdot 16 + 9 \cdot 16)\ ft^2 = 912\ ft^2$

Epoxy Injection $EI_{P6} := 50\ ft$

Pier 6 Repairs Cost:

$$Cost_{P6} := RP_{P6} \cdot \frac{65}{ft^2} + RC_{P6} \cdot \frac{800}{ft^2} + CR_{P6} \cdot \frac{150}{ft} + CP_{P6} \cdot \frac{147}{ft^2} + EI_{P6} \cdot \frac{107}{ft} = 624562$$

Use $620,000 LS

## Abutment_7:

The plans show the face of the existing stone abutment is 18.75ft wide. The height is measured in the pictures as 9.5ft. The new stone from the 1950s is in good condition.

$$SA_{SF} := 18.75\ ft \cdot 9.5\ ft = 178.1\ ft^2$$

Abutment 7 Total Surface Area: $\boxed{AB_7 := SA_{SF} = 178.1\ ft^2}$

Repairs to Abutment 7:

The east face has 3 areas of deterioration that need to be reconstructed. All three are sections are about 4ft wide and full height. The sections are on each end and at the middle. Conserv. add 20ft of crack repair.
Concrete spalling and delamination on the south face, 4ft by 8ft and 3ft by 10ft.
Spalling on the backwall 15sqft.
Assume 30ft for cracking repair.

Reconstruct: $RC_{A7} := 3 \cdot 4\ ft \cdot 9.5\ ft = 114\ ft^2$

Crack Repair: $CR_{A7} := 20\ ft = 20\ ft$

Repoint: $RP_{A7} := AB_7 - RC_{A7} = 64.1\ ft^2$

Concrete Patching: $CP_{A7} := (4 \cdot 8 + 3 \cdot 10 + 15)\ ft^2 = 77\ ft^2$

Epoxy Injection $EI_{A7} := 30\ ft$

Abutment 7 Masonry Repairs Cost:

$$Cost_{A7} := RP_{A7} \cdot \frac{65}{ft^2} + RC_{A7} \cdot \frac{800}{ft^2} + CR_{A7} \cdot \frac{150}{ft} + CP_{A7} \cdot \frac{147}{ft^2} + EI_{A7} \cdot \frac{107}{ft} = 112897$$

Use $110,000 LS

# 5. Substructure-Concrete Encasement Repair

For comparison to the full historic rehabilitation option, only consider encasement from waterline or groundline up.

Concrete Encasement Thickness: $Conc := 18\ in$

A pier encasement job was done in Floyd Co., KY by KYTC Division of Maintenance. Combine all the related costs into a single repair.

Pier Repair = $85/sqft
Blast Clean = ($45/sqyd)/9 = $5/sqft
Steel Reinforcement = $3/lb * 10,967LB / 920SQFT = $36/sqft

Pier Encasement Unit Cost = $85+$5+$36 = $126/sqft

Determine encasement cost based on 2018 average unit steel and rebar cost

Class AA Concrete = $733.26/CUYD*(1CUYD/27CUFT)*(1.5ft*1ft*1ft)/1sqft = $40.7/sqft
Steel Reinforcement = $1.08/LB *(200LB/1CUYD)*(1CUYD/27CUFT)*(1.5CUFT/1SQFT) = $12/sqft
Blast Clean = $8.92/SQYD*(1SQYD/9QSFT) = $1.0/sqft

Pier Encasement Average Unit Costs = $41+$12+$1 = $54/sqft

Use $125/sqft in Broadway Bridge cost estimate

## Abutment_1:

There are popouts and scaling thoughout the abutment surface, assume 90sqft of patching.
Spalling with exposed rebar of the backwall, 10sqft.
Crack repairs, 50ft.

Concrete Patching: $CP_{A1} := 90\ ft^2 + 10\ ft^2 = 100.00\ ft^2$

Epoxy Injection $EI_{A1} := 50\ ft$

Repair Cost: $Cost_{A1} := CP_{A1} \cdot \frac{147}{ft^2} + EI_{A1} \cdot \frac{107}{ft} = 20050$

Use $20,000 LS

## Pier_2:

No repairs needed

## Pier_3:

$SA_{EF} := (25\ ft) \cdot 8.88\ ft = 222\ ft^2$

$SA_{WF} := (25\ ft) \cdot (19.5\ ft) = 487.5\ ft^2$

North and south face doesnt have a good straight on pic so estimate from plans that pier point is 4ft x 4ft. Use an average of the EF and WF Heights. Assume 4.5ft by 4.5ft triangle at base.

$$SA_{END} := 2 \cdot \left( \frac{\sqrt{2 \cdot 4^2}\ ft + \sqrt{2 \cdot 4.5^2}\ ft}{2} \right) \cdot \left( \frac{8.88\ ft + 19.5\ ft}{2} \right) = 170.6\ ft^2$$

Pier 3 Total Surface Area: $\boxed{P_3 := SA_{EF} + SA_{WF} + 2 \cdot SA_{END} = 1050.7\ ft^2}$

Repairs to Pier 3:

Repair the concrete cap on top of the stone, 73 sqft. The ditch in the cap is 3ft wide by 8ft long, 24 sqft. Encase entire surface area.

Concrete Patching: $CP_{P3} := 73\ ft^2 + 24\ ft^2 = 97\ ft^2$

Epoxy Injection: $EI_{P3} := 0\ ft$

Concrete Encasement: $CE_{P3} := P_3 = 1050.7\ ft^2$

Pier 3 Repair Cost:

$$Cost_{P3} := CP_{P3} \cdot \frac{147}{ft^2} + EI_{P3} \cdot \frac{107}{ft} + CE_{P3} \cdot \frac{125}{ft^2} = 145590$$

Use $150,000 LS

## Pier_4:

Repair the heavy efflorescencse with concrete patching and the other cracks with epoxy injection. There are no major spalls. Neglect deterioration under adjacent railroad bridge.
East face - 4ft by 10ft.
West face - 8ft by 8ft and 4ft by 4ft.
North face - 4ft by 4ft.
Crack repair - 150ft

Concrete Patching: $CP_{P4} := (4 \cdot 10 + 8 \cdot 8 + 4 \cdot 4 + 4 \cdot 4)\ ft^2 = 136\ ft^2$

Epoxy Injection: $EI_{P4} := 150\ ft$

Pier 4 Repair Cost:

$$Cost_{P4} := CP_{P4} \cdot \frac{147}{ft^2} + EI_{P4} \cdot \frac{107}{ft} = 36042$$

Use $36,000 LS

## Pier_5:

$$SA_{EF} := \frac{(25.5\ ft + 38.5\ ft)}{2} \cdot 31.5\ ft = 1008\ ft^2$$

Assume the end point is at a 45 degree angle. At the top the width is 8ft and 14.ft at the base. Use half of these widths for the legs of the triangle.

$$SA_{END} := 2 \cdot \left( \frac{\sqrt{2 \cdot 4^2}\ ft + \sqrt{2 \cdot 7^2}\ ft}{2} \right) \cdot (31.4\ ft) = 488.5\ ft^2$$

Pier 5 Total Surface Area: $\boxed{P_5 := SA_{EF} \cdot 2 + SA_{END} \cdot 2 = 2992.9\ ft^2}$

Repairs to Pier 5:

The entire concrete cap was replaced when the bridge was reconfigured so there are only minor concrete repairs. Assume 10sqft patching and 20ft of crack repairs. Encase entire surface area.

Concrete Patching: $CP_{P5} := 10\ ft^2 = 10\ ft^2$

Epoxy Injection: $EI_{P5} := 20\ ft$

Concrete Encasement: $CE_{P5} := P_5 = 2992.9\ ft^2$

Pier 5 Repair Cost:

$$Cost_{P5} := CP_{P5} \cdot \frac{147}{ft^2} + EI_{P5} \cdot \frac{107}{ft} + CE_{P5} \cdot \frac{125}{ft^2} = 377727$$

Use $380,000 LS

## Pier 6:

Due to the picture taken at the water level and looking up the width at the base of the pier is inflated so use 60ft wide at the base.

$$SA_{EF} := \frac{(51\ ft + 60\ ft)}{2} \cdot 27\ ft = 1498.5\ ft^2$$

Use an average width of 53ft for the WF and estimate the height at each end and the middle.

$$SA_{WF} := 53\ ft \cdot \left(\frac{10\ ft + 6\ ft + 12\ ft}{3}\right) = 494.7\ ft^2$$

From the plans the pier is 13'-2" wide at the cap and the pictures show that at about 10ft above the water line the pier widens to about 16ft. Assume both faces are the same.

$$SA_{END} := 13.17\ ft \cdot (27\ ft - 10\ ft) + 16\ ft \cdot 10\ ft = 383.9\ ft^2$$

Pier 6 Total Surface Area: $\boxed{P_6 := SA_{EF} + SA_{WF} + SA_{END} \cdot 2 = 2760.9\ ft^2}$

Repairs to Pier 6:

The east face has 9 full height cracks and 20sqft of stone to be reconstructed.
The east face concrete has heavy deterioration, repair half the face 32ft by 8ft.
The west face concrete has heavy deterioration, repair entire face 32ft by 16ft.
Assume half the side faces need cocnrete repair, 9ft by 16ft.
Assume 50ft epoxy injection crack repair.
Encase west face.

Reconstruct: $RC_{P6} := 20\ ft^2 = 20\ ft^2$

Crack Repair: $CR_{P6} := (9) \cdot 27\ ft = 243\ ft$

Concrete Patching: $CP_{P6} := (32 \cdot 8 + 32 \cdot 16 + 9 \cdot 16)\ ft^2 = 912\ ft^2$

Epoxy Injection $EI_{P6} := 50\ ft$

Concrete Encasement: $CE_{P6} := SA_{WF} = 494.7\ ft^2$

Pier 6 Repair Cost:

$$Cost_{P6} := RC_{P6} \cdot \frac{800}{ft^2} + CR_{P6} \cdot \frac{150}{ft} + CP_{P6} \cdot \frac{147}{ft^2} + EI_{P6} \cdot \frac{107}{ft} + CE_{P6} \cdot \frac{125}{ft^2} = 253697$$

Use $250,000 LS

## Abutment_7:

The plans show the face of the existing stone abutment is 18.75ft wide. The height is measured in the pictures as 9.5ft. The new stone from the 1950s is in good condition.

$$SA_{EF} := 18.75\ ft \cdot 9.5\ ft = 178.1\ ft^2$$

Abutment 7 Total Surface Area: $\boxed{AB_7 := SA_{EF} = 178.1\ ft^2}$

Repairs to Abutment 7:

Concrete spalling and delamination on the south face, 4ft by 8ft and 3ft by 10ft.
Spalling on the backwall 15sqft.
Assume 30ft for epoxy injection crack repair.
Encase total masonry surface area.

Concrete Patching: $CP_{A7} := (4 \cdot 8 + 3 \cdot 10 + 15)\ ft^2 = 77\ ft^2$

Epoxy Injection $EI_{A7} := 30\ ft$

Concrete Encasement: $CE_{A7} := AB_7 = 178.1\ ft^2$

Abutment 7 Repair Cost:

$$Cost_{A7} := CP_{A7} \cdot \frac{147}{ft^2} + EI_{A7} \cdot \frac{107}{ft} + CE_{A7} \cdot \frac{125}{ft^2} = 36795$$

Use $37,000 LS

# 6. 12' Wide Concrete Deck Pedestrian Path

## Class_AA_Concrete:

Volume assumes a 12 ft wide, 7 in thick deck with 1ftx6in concrete curbs.

$$Vol := (7 \cdot in \cdot 12 \cdot ft + 2 \cdot 1 \cdot ft \cdot 6 \cdot in) \cdot (169 + 336) \cdot ft = 150\ yd^3$$

2018 average unit bid price for Class AA Concrete will be increased by 10% for estimate.

$$Bid_{AA} := 1.1 \cdot 733.26 = 806.586$$

Use $800 per CY

## Steel_Reinforcement_Epoxy_Coated:

Assume 180 lb per cy from KSU pedestrian bridge.

$$Rebar := \frac{Vol \cdot 180}{yd^3} = 26933$$

2018 average unit bid price for Steel Reinforcement Epoxy Coated will be increased by 10% for estimate.

$$Bid_{Rebar} := 1.1 \cdot 1.18 = 1.298$$

Use $1.30 per LB

## Metal_Pedestrian_Railing:

$$Railing := 2 \cdot ((169 + 336) \cdot ft) = 1010\ ft$$

Use $100 per LF for railing based on bids for KY Lake and Lake Barkley

# 7. 10' Wide Timber Deck Pedestrian Path

## Timber_Decking:

Area assumes a 10 ft wide timber deck.

$$Area := (10 \cdot ft) \cdot (169 + 336) \cdot ft = 5050\ ft^2$$

Use $20 per SF for deck cost based on conversations with boardwalk estimators.

## Timber_Pedestrian_Railing:

$$Railing := 2 \cdot ((169 + 336) \cdot ft) = 1010\ ft$$

Use $30 per LF for railing based on conversations with boardwalk estimators.

# 8. New Construction 12' Wide Pedestrian Bridge

Use KSU Pedestrian Bridge as a lower-bound cost estimate

That bridge is on drilled shafts, has PC Box Beams, and included aesthetic considerations.

Proposed new pedestrian bridge is assumed to be:

550 ft long
PC Box Beams for approach spans
Prefabricated truss for the main span
12 ft useable width

Due to additional costs of construction over the KY River, use $250 per SF

$$Cost_{NC} := 550 \cdot 12 \cdot 250 = 1650000 \quad dollars$$

# 9. Demolition - Concrete Deck

## Counter-Diagonal_Stabilization:

Counter diagonals will need to be stabilized or temporarily repaired before the deck is removed. This does not need to be as robust as a permanent retrofit. For example, the contractor could opt to weld cover plates on top of the damaged connection plates could as a temporary repair to allow for deck removal.

Use $15,000 LS

## Demolition_-_Concrete_Deck

Use contractor's estimated total costs, coupled with costs on similar projects of known complexity and risk. Break costs down to a cost per SF.

Contractor 1 = $100k + $50k for barges + $40k for RR costs = $190k

$$SF_{C1} := \frac{190000}{14061} = 13.5126$$

Contractor 2 = Guess between $400k and $600k = $500k

$$SF_{C2} := \frac{500000}{14061} = 35.5593$$

KYTC Cumberland County KY61 and KY90 = $38.50 per SF

TDOT Hancock County TN 70 = $18.75 per SF

$$SF_{Average} := \frac{13.51 + 35.56 + 38.5 + 18.75}{4} = 26.58 \text{ dollars per SF}$$

If the total deck removal cost was $375k, what would the cost be per SF?

$$SF_{375k} := \frac{375000 - 15000}{14061} = 25.6 \text{ dollars per SF}$$

Since this is very close to the average, use a lump sum estimate of $360k

# 10. Demolition - Superstructure

Contractor 1 = $300k + $50k for barges + $40k RR costs = $390 k

Contractor 2 = Between $1.0M and $1.5M = $1.25M

$$AVG := \frac{390000 + 1250000}{2} = 820000$$

Palmer Engineering independent estimate is $600k. Since this is between the two contractor estimates, and slightly less than the average of the two contractors, say OK to use $600k.