US 51 Ohio River Bridge Engineering and Environmental Study

ITEM NOS. 1-100.00 & 1-1140.00

Bridge Concepts Fact Sheet

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August 16, 2013

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EXECUTIVE SUMMARY

The purpose of this white paper is to inform the reader about the structural "Rehabilitation" and "Replacement" alternatives for the existing bridge. Appropriate actions can then be developed for an approved environmental document to either repair or replace the existing bridge. Bridge concepts considered for this phase of the project are Tied Arches, Box Girders, Cable Stay, and Through Truss bridges. This document should be considered in the context of the environmental study and is not intended to be a standalone evaluation of the concepts.

Alternative 1 – Superstructure replacement

- Preliminary analysis indicates that re-use of the existing piers may be feasible, however additional study is necessary.
- Extensive rehabilitation of the piers would be required to meet the requirements for seismic and vessel collision events.
- Preserves the existing navigation span arrangement at 800ft and 650ft and would reduce the amount of new construction associated with the longer alternatives presented.
- Through Truss and Arch Bridges are both feasible for this alternative.

Alternative 2, 2A, 2B

- Located just upstream of the existing bridge between RM 980.0 and 980.4
- USCG requires a 900ft horizontal clearance and vertical clearance of at least 105.3 feet
- Cable Stay, Truss and Arch Bridges are all suitable bridge types.
- Existing US-51 Bridge would be demolished and removed.

Alternative 3, 3A

- Located just upstream of the existing Illinois Central RR bridge between RM 977.7 and 977.4
- USCG requires a 1,200ft horizontal clearance and vertical clearance of at least 105.3 feet
- Cable Stay is the recommended bridge type for this location.
- Existing US-51 Bridge would be demolished and removed.

Alternative 4 and 5

- Located upriver of the existing Illinois Central RR bridge at RM 977.0 and 973.0 respectively
- USCG requires a 1,000ft horizontal clearance and vertical clearance of at least 105.3 feet
- Cable Stay, Truss and Arch Bridges are all suitable bridge types.
- Existing US-51 Bridge would be demolished and removed.

Approach Spans
The approach structures would likely be steel multi-girder for spans of 150 to 400 ft. or concrete beam for spans of 100 to 150 ft. on new piers utilizing continuous units and efficient span arrangements as much as possible. Portions of approach span bridge located over the Ohio River would likely be long span welded plate girders to minimize the number of piers in the waterway.

For the cost estimates of the new bridge alignments 2, 2A, 2B, 3, 3A, 4 and 5, square foot costs from similar cable stayed bridge projects were used as the basis of the estimate. The cable stay bridge is thought to be a very representative economic structure in the span ranges required for this project. Because of the unique site conditions and proximity to the New Madrid Fault, it is recommended that additional engineering analysis be performed to determine the most suitable bridge type for this site.

Figure 1 – Level 2 Alternatives

1. Ohio River Bridge Concepts

For the current Alignment Alternatives 1, 2, 2A, 2B, 3, 3A, 4 and 5, through truss, through arch, cable stayed and concrete box girder bridge types have been evaluated, to rehabilitate or replace the structurally deficient and functionally obsolete US-51 Bridge over the Ohio River at Cairo, Illinois. Reasonable assumptions and comparisons of bridge types from previous Ohio River Bridge projects were used in the decision making process. See Figure 1 for alignments of the alternatives being considered.

Cost estimates have been prepared for the alignments based on historical square foot costs of similar bridges. While this method is very useful, it does have limitations with respect to drawing conclusions from sites that may be different than the one under consideration. The square foot cost estimates of the various structure types investigated were modified to take into account the depth of scour and depth of deep foundations. This is due to the site geotechnical conditions and the requirement of a site specific seismic analysis with either a 2,500 or 1,000 year return interval due to the proximity of the New Madrid Fault, along with the structure being a critical and essential bridge over the Ohio River. These assumptions and concerns will require further investigations as this project moves forward.

For the cost estimates of the new bridge alignments 2, 2A, 2B, 3, 3A, 4 and 5, square foot costs from similar cable stay bridge projects were used as the basis of the estimate. The cable stay bridge is thought to be a very representative economic structure in the span ranges required for this project. Because of the unique site conditions and proximity to the New Madrid Fault, it is recommended that additional engineering analysis be performed to determine the most suitable bridge type for this site.

2. Alignment Alternative 1 – Superstructure Replacement using the existing piers

With this alternative, the existing River Bridge piers would be widened and strengthened for current AASHTO seismic and barge impact requirements and reused. This would allow for a wider superstructure to be placed on top and a strengthened shaft and foundation to resist governing seismic forces mentioned above. A preliminary pier strengthening concept is shown in Figure 2. The existing pier shafts require a reinforced concrete encasement approximately 2 feet thick to be constructed around the existing river pier shafts and a steel pipe pile supported reinforced-concrete footing approximately 16 feet thick around each foundation.

US Coast Guard approval is required for reducing the center channel by approximately 4 feet for the pier shaft encasement from 630 feet to about 626 feet and reducing the Illinois channel by 4 feet from 780 feet to about 776 feet. To minimize the reduction to the channel, foundation modifications would be located below water at the top of the caisson. The preliminary top of footing would provide 12ft of draft for navigation approximately 85% of the time. During low water events the draft would not be maintained and during extreme low water the footing may become exposed. Acceptable draft requirements have not been established by the US Coast Guard at this current phase of the project.

The US Coast Guard also has the following vertical clearance requirement for all alternatives for superstructure low steel and they must provide a vertical clearance of at least 105.3 feet above zero on the Cairo gage.

- 55 ft. above the 2% flood, low steel Elev. = (Elev. 321.0 ORD + 55 ft. = Elev. 376.0 ft. ORD)
- 69 ft. above June flow, low steel Elev. = (Elev. 298.1 ORD + 69 ft. = Elev. 367.1 ft. ORD)

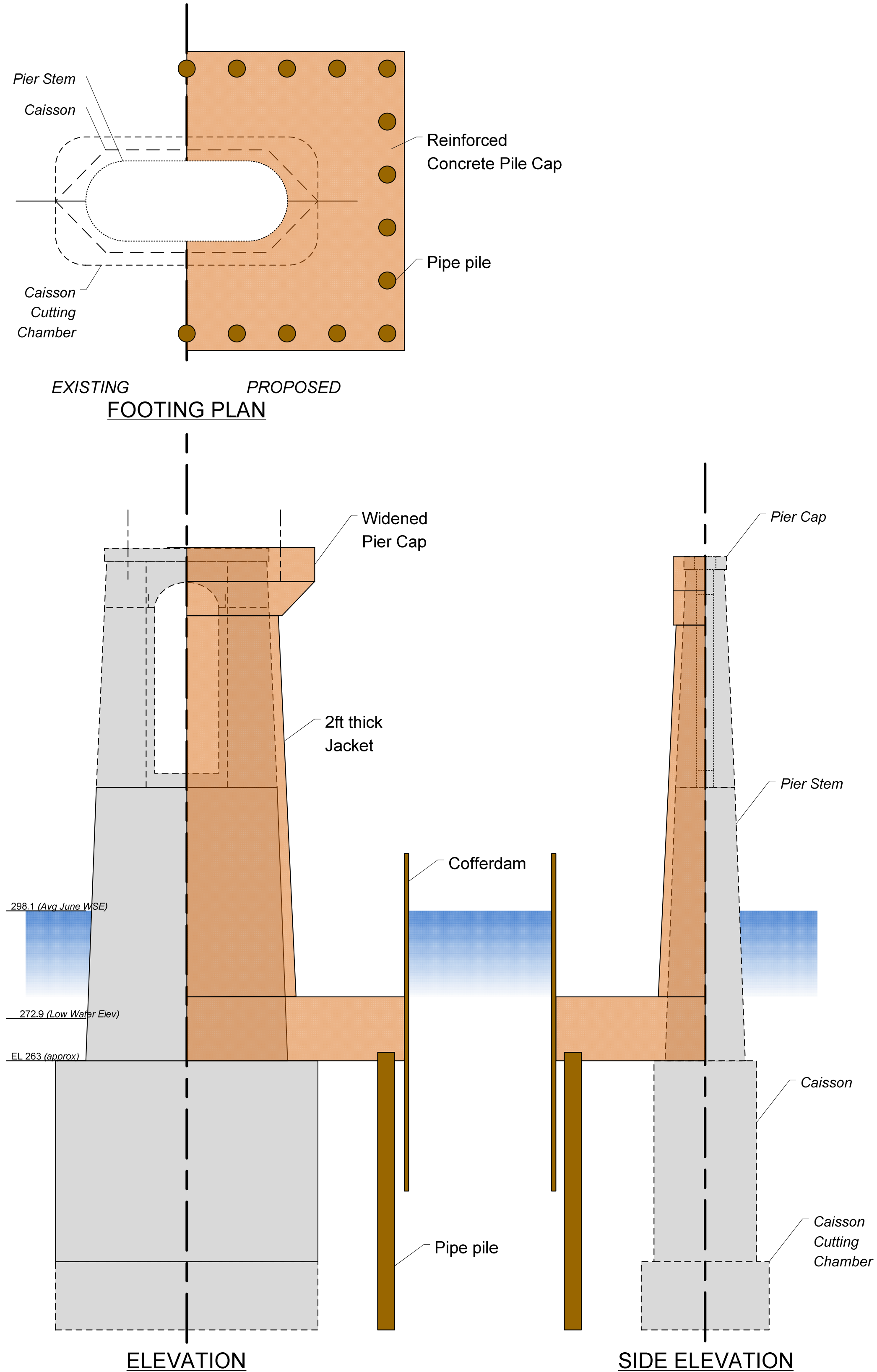

Figure 2 - ALT 1 Pier Strengthening Concept

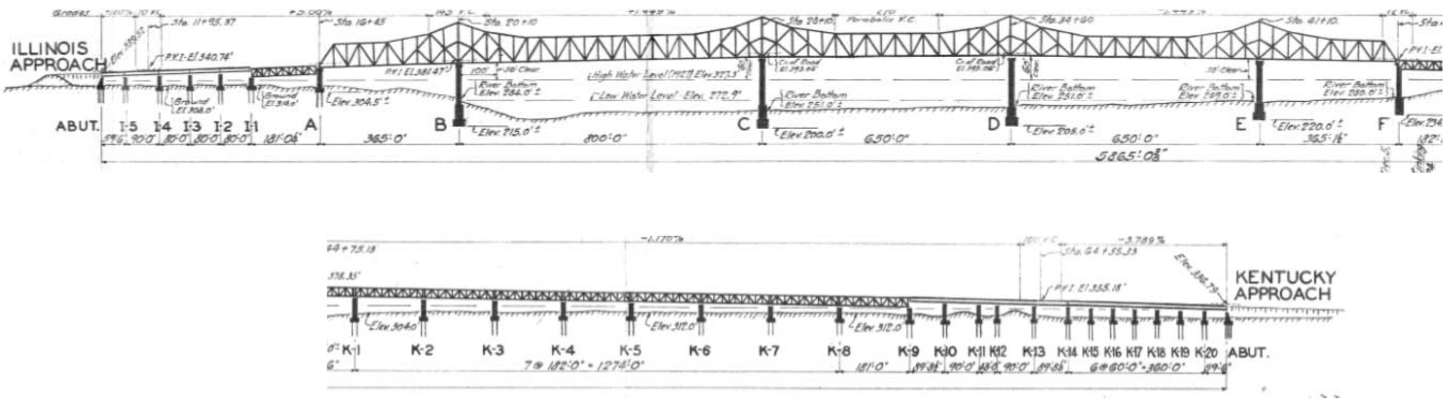

Figure 3 – Existing Bridge Layout

Through Truss Bridge Type

A conventional variable depth Warren truss with verticals and a parallel chord Warren truss without verticals were considered for the river structure, spanning from Piers A through F (shown in Figure 3). The approach structures would either be steel multi-girder for spans of 150 to 400 ft. or concrete beam for spans of 100 to 150 ft. on new piers utilizing continuous units and efficient span arrangements as much as possible. The proposed approach span replacement costs, excluding demolition, are in the range of $185 to $235 per square foot depending on site specific factors such as seismic requirements, substructure geometry and foundation types. Shorter spans with limited beam depths or through type structures are necessary over the railroads to meet vertical clearance requirements. The locations of the existing approach span piers would not result in efficient continuous beam span arrangements and would require costly rehabilitation for the wider superstructure for reuse and therefore are recommended to be replaced.

The variable depth Warren truss has a great deal of visual clutter due to the combination of verticals and diagonals necessary for the efficient design of the truss, whereas the parallel chord truss is open, visually clean and has favorable aesthetics. Therefore, a parallel chord truss bridge would be appropriate for Alternative 1. There would be some variation in the depth of the parallel chords from about 80 ft. to about 65 ft. between the 800 ft. span and 650 ft. spans respectively for cost efficiency.

The following components make up the superstructure geometry of the through truss bridge type:

- cast-in-place conventionally reinforced concrete deck slab and parapets
- longitudinal stringers directly supporting the slab
- floorbeams at each truss panel point that transfer the load of the stringers and deck slab to each panel point
- two main truss systems consisting of top and bottom chords and diagonals
- lateral bracing in each plane of the top and bottom chord
- portal frames (end sway frames).
- intermediate sway frames

The construction costs for both truss alternatives are comparable for this level of evaluation. Both 50 ksi and 70 ksi steel would be used to decrease member size and therefore lessen the effects of dead load on the existing piers A through F.

Erection of the main spans and side spans would most likely occur in a balanced cantilever from each main pier simultaneously. Either tie-downs, falsework bents or a combination of the two systems would be necessary to ensure stability of the partially constructed truss. Falsework bents and tie-downs would be placed in a manner that does not restrict navigational use of the Ohio River (primary) channel. Accelerated construction techniques have been used to construct trusses, including floating and lifting completed portions of the bridge into place. Lateral sliding is another technique that can possibly also be utilized.

Long Span through trusses are some of the most difficult bridge structures to maintain and inspect. High performance painting systems are usually required due to the direct exposure of much of the bridge to splash zones from vehicular traffic. In addition, the three-dimensional junction of truss chords, diagonals, lateral bracing and portal bracing are areas difficult to access and maintain. Fixed ladders and inspection walkways would be provided for ease of inspection for some of the deck and truss members. The use of mobile inspection equipment, such as snoopers with lane closures for inspection of areas not accessible by ladders and inspection walkways, is somewhat problematic due to interference created by main truss diagonals.

Through Arch Bridge Type

Conventional through tied arches with vertical suspender cables and more modern networked and basket-handle tied arches with skewed suspender cables were considered for the River Structure spanning the three spans supported by Piers B through E thus limiting the length of the more expensive river structure. Continuous steel multi-girder or concrete beam approach spans on new piers with efficient span arrangements should be utilized as much as possible to result in a very cost efficient alternative. Piers B through E would be rehabilitated as discussed above and Piers A and F, and all other approach span piers are assumed to be replaced with new piers.

In general, the arch solution is a clean and open form and has minimal impact of the view shed. The networked tied arch has the same openness and visual clarity of the conventional arch but is more efficient and requires less structural steel that lessen the effects of dead load on the existing piers B through E, the networked tied arch would be appropriate for this location for Alternative 1. The arch height would be about 160 ft. for the 800 ft. span and about 130 ft. for the 650 ft. spans.

The following components make up the superstructure geometry of tied arch alternative:

- cast-in-place conventionally reinforced concrete deck slab and parapets
- longitudinal stringers directly supporting the slab
- floorbeams to transfer the load of the stringers and deck slab to each tie girder.
- two main arch systems consisting of the arch rib, hanger cables and tie girder
- lateral bracing between the upper arch ribs and lower lateral bracing at the floor system

Arch rib members and tie girder members can either be box or "H" shaped. Arch tie girders are considered fracture critical and are required to meet AASHTO material toughness and fracture critical fabrication requirements along with having internal redundancy by bolting rather than welding tie girder webs and flanges together. The tied arch would also have to de designed for cable loss.

The construction cost for both arch alternatives are comparable for this level of evaluation. A networked tied arch would require less steel but would have increased fabrication costs due to the skewed suspender cables and connections. 50 ksi steel would be considered for the floor system and 70 ksi steel would be considered for the arch rib and tie girder system for increased toughness and to decrease member sizes, therefore lessening the effects of dead load on the existing piers B through E.

An erection advantage of the tied arch is that in recent years, arches have been assembled off site, floated in and then lifted into place. The conventional erection method would require falsework at each pier so that the first portion of the arch, tie beam and floorsystem can be supported during construction. Once the first portion is erected, towers and tie-back cables can support the remainder of arch construction from the existing piers. Falsework would be placed in a manner that does not restrict navigational use of the Ohio River (primary) channel.

In terms of maintenance and serviceability, arches are similar to trusses. Arches have only a small portion of the arch rib in the splash zone limiting the overall exposure of the steel portion of the bridge to a highly corrosive environment. Tie girders are subjected to direct tension with bending, and are considered fatigue sensitive elements. Recent tied arch bridges incorporate a fully redundant tie system in order to provide an alternate load path in the event of a tie component failure.

For arches composed of box ribs and tie girders, inspection access is provided inside the arch rib and tie girders for inspection with a series of access holes and fixed ladders where required. Mobile inspection equipment, such as snoopers with lane closures, is used for inspections of all other areas. An inspection walkway can also be provided under the floor system.

Cable Stayed Bridge Type

A Cable Stayed Alternative was considered for the River Structure, spanning Piers A through F. The four towers would be approximately 180ft. high and constructed on existing Piers B through E. Piers A and F would support the end spans of the balanced cable stayed unit and all other approach span piers would be replaced with new piers to support the steel multi-girder or concrete beam approach spans similar to the Through Truss Alternative.

Due to the inherent flexibility of cable stayed bridges, a wide range of aesthetic possibilities exist and are primarily dependent upon stay cable geometry and pylon shape. H-shaped pylons with two vertical planes of cables and A-shaped pylons with two inclined planes of cables were considered because of the narrow bridge superstructure width. It is also assumed the cables will be configured in a semi fan cable configuration. Steel and concrete edge girder alternatives were considered to provide the required vertical clearance for navigation.

The success of this bridge form in the 600 ft. to 2000 ft. range is primarily due to its inherent ease of constructability. Cable stayed bridges are customarily erected by the balanced cantilever method of erection after the tower and initial deck segment at the tower are constructed.

Cable stayed bridges offer substantial improvements for maintenance and serviceability over truss and arch alternatives. Painting is required only for steel edge girder alternatives and can be eliminated if weathering steel is utilized. Since all structural steel is below the deck and out of the vehicle splash zone, properly applied high performance painting systems should have an excellent service life.

Vibration induced by wind and rain-wind combinations has been a serviceability issue over the past 30 years, but recent code developments, coupled with a better understanding of the mechanisms responsible for stay cable vibrations, have virtually eliminated this problem.

Due to the difficulties and cost associated with deck replacement of cable stayed bridges because the deck is an integral element resisting compression forces imparted by stay cables, high performance overlays such as epoxy are typically required to extend the deck service life. Cable stayed bridges require design for future deck replacement and are designed for cable loss similar to tied arches.

Cable stayed bridges are among the easiest bridges to inspect when complete access to all elements, except cables, can be provided by fixed ladders and inspection walkways. The use of mobile inspection equipment can be a little problematic due to interference created by the stay cables.

Both the steel and concrete edge girder cable stayed bridges are considered the most economical cable stayed alternatives for the site. However, the extremely high cost of strengthening or essentially replacing the existing piers to accept the tower loads eliminates this bridge type from further consideration for Alignment Alternative1 – Superstructure Replacement using the existing piers.

Concrete Box Girder Bridge Type

Both Cast-in-Place Concrete Box Girders and Segmental Concrete Box girders would require a superstructure depth of approximately 30 feet at the river piers and 10 feet at mid-span and therefore would have an adverse effect on the proposed profile grade due to providing the required vertical clearance for navigation. This bridge type was therefore eliminated from consideration for Alignment Alternative 1.

3. Alignment Alternatives 2, 2A and 2B – New Alignment

These alignments are located just upstream of the existing bridge. All three of these alternatives between Ohio River Mile Points 980.0 and 980.4 would serve the same function and result in similar impacts. After construction of this alternate, the existing US-51 Bridge at Ohio River Mile Point 980.4 would be demolished and removed. We have reviewed the clear span of the existing bridges on the Ohio River in Kentucky, including the proposed cable stayed bridges at Louisville and the new bridge at Cape Girardeau on the Mississippi River, and have recommended a 900 ft. horizontal clearance envelope perpendicular to the sailing line at this location. Additional navigation clearance is available in the 200 ft. side spans. The US Coast Guard requirements for this alternative are as follows:

- 900 ft. main channel horizontal clearance adjacent to the sailing line
- 105.3 ft minimum vertical clearance required in channel

Bridge Types Considered
The required clearance of 900 ft. for the main span of the bridge can be accommodated by the tied arch, through truss, or cable stayed bridge. Steel Plate Girder approach spans would be utilized over the remaining section of the river to reduce the number of piers constructed in the river.

Arch Bridge
Single 925 ft. tied arch span
Approx. 180 ft. high

Cable Stayed Bridge
Span Arrangement of 380' - 950' - 380'
Approx. tower height above deck, 200 ft.
Steel Plate Girder approaches over rest of the river

Through Truss
Span Arrangement 450' - 950' - 450'
Approx. 70 ft. depth

Concrete Box Girder
Not recommended due to main span length and required depth of structure.

4. Alignment Alternatives 3 and 3A – New Alignment

Alternatives 3 and 3A share the same river crossing and Illinois approach location but different Kentucky approach locations. These alignments are located just upstream of the existing Illinois Central Railroad bridge between Ohio River Mile Mark 977.7 and 977.4. After construction of this alternate, the existing US-51 Bridge at Ohio River Mile Point 980.4 would be demolished and removed. A clear span of slightly more than 1,200 feet would be required at this location to line up proposed piers with the existing railroad bridge piers. The span layout would line up the right descending pier of the proposed bridge with the right descending pier of the railroad bridge on the Illinois Bank. The US Coast Guard requirements for this alternative are as follows:

- 1200 ft. main channel horizontal clearance lined up with the existing railroad bridge piers
- 105.3ft minimum vertical clearance required in channel

Bridge Types Considered
The required clearance of 1200 ft, for the main span of the bridge can be accommodated by the tied arch, or cable stayed bridge. Steel Plate Girder approach spans would be utilized over the remaining section of the river to reduce the number of piers constructed in the river.

Arch Bridge
Three Single 1,225 ft., 500 ft., 500 ft. tied arch spans
Approx. 240 ft. high
Steel Plate Girder approaches over rest of the river

Cable Stayed Bridge
Span Arrangement of 500' - 1225' - 500'
Approx. tower height above deck, 300 ft.
Steel Plate Girder approaches over rest of the river

Through Truss
Not recommended due to main span length

Concrete Box Girder
Not recommended due to main span length and required depth of structure.

5. Alignment Alternatives 4 and 5 – New Alignment

These alignments are located further upstream of the existing Illinois Central Railroad bridge between Ohio River Mile Marks 977.0 and 973.0 and have similar main river span arrangements. After construction of this alternate, the existing US-51 Bridge at Ohio River Mile Point 980.4 would be demolished and removed. The US Coast Guard navigational requirements for these two alternatives are as follows:

- 1,000 ft. main channel horizontal clearance adjacent to the sailing line
- 105.3 ft minimum vertical clearance required in channel

Bridge Types Considered
The required clearance of 1,000 ft, for the main span of the bridge can be accommodated by the tied arch, through truss, or cable stayed bridge. Steel Plate Girder approach spans would be utilized over the remaining section of the river to reduce the number of piers constructed in the river.

Arch Bridge
Single 1,025 ft. tied arch span
Steel Plate Girder approaches over rest of the river

Cable Stayed Bridge
Span Arrangement of 410' - 1025' - 410'
Approx. tower height above deck, 200 ft.
Steel Plate Girder approaches over rest of the river

Through Truss
Possible, but at the upper limit for truss spans

Concrete Box Girder
Not recommended due to main span length and required depth of structure.

6. Alternatives for Further Consideration

The Truss, Arch and Cable Stayed Bridge Types proposed as described for Alignment Alternatives1, Combined 2, 3A, and 4 are the most favorable alternatives for initial construction costs, constructability, maintenance, serviceability inspectability and therefore recommended for further consideration in the next phase of this project.

The alternatives are further summarized as follows:

Alternative 1 – Superstructure replacement

Preliminary analysis indicates that re-use of the existing piers may be feasible, however additional study is necessary. Extensive rehabilitation of the piers would be required to meet the requirements for seismic and vessel collision events. Through Truss and Arch Bridges are both feasible for the 800 ft. and 650 ft. spans required for this alternative.

Alternative 2, 2A, 2B

Cable Stay, Truss and Arch Bridges are all suitable bridge types for the 900 ft. horizontal clearance and vertical clearance of at least 105.3 feet.

Alternative 3, 3A

Cable Stay is the recommended bridge type for this location for the 1,200 ft. horizontal clearance and vertical clearance of at least 105.3 feet.

Alternative 4 and 5

Cable Stay, Truss and Arch Bridges are all suitable bridge types for the 1,000 ft. horizontal clearance and vertical clearance of at least 105.3 feet.