THE NEW NY (TAPPAN ZEE) BRIDGE: WHY STEEL PROVIDED THE OPTIMUM SOLUTION

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BIOGRAPHY

Kenneth J. Wright, P.E. is a Senior Vice President/Senior Project Manager with HDR. He is currently assigned to HDR's New York Department as the Design Manager for the $3.142 billion Tappan Zee Bridge Replacement. Prior to his current assignment, he was the structures section manager in HDR's Pittsburgh office and the Transportation Business Group Manager for Pennsylvania/West Virginia/Ohio.

He earned a BSCE from Lehigh University in 1982 and has been with HDR for nearly 32 years. He also earned an MBA from Baker College in 2007. He is a registered PE in 7 states. He has presented at numerous conferences, including at past WSBS events.

SUMMARY

The New NY Bridge (Tappan Zee Bridge) is the largest transportation design-build project bid to date in the United States at $3.142 billion. It is also the first transportation project delivered using the design-build delivery system in New York State as there had not been enabling legislation for design build until late 2011. The project is replacing a key link in the New York highway system that carries nearly 140,000 vehicles daily. The replacement structure actually provides separate structures for redundancy and to significantly increase capacity. The best value design-build approach resulted in significant savings for the NY State Thruway Authority.

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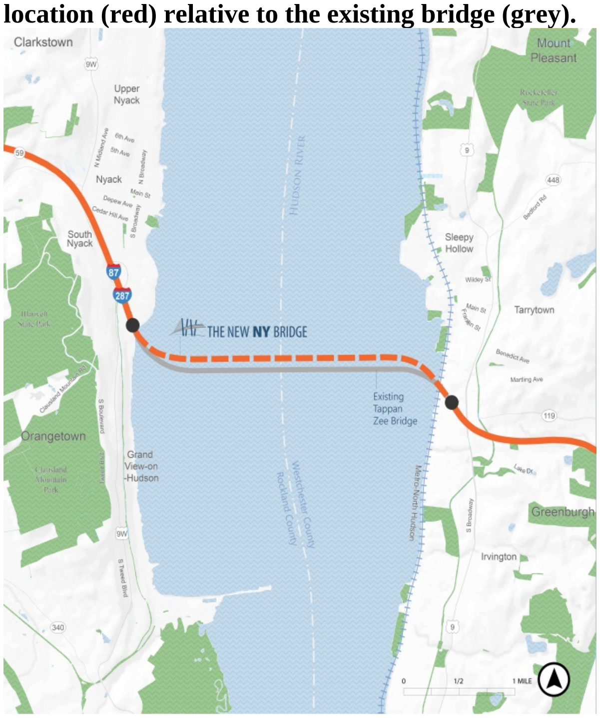
Introduction

The New NY (Tappan Zee) Bridge is a 3.1 mile bridge crossing the Hudson River between Rockland and Westchester Counties approximately 25 miles north of New York City (See Figure 1). The bridge begins from the west shore as a low causeway bridge above the river with 169 – 50’ simple spans, transitioning to deck trusses with longer spans approaching the main shipping channel bridge. The main channel bridge is a three-span truss with a 1200’ main span and anchor spans of approximately 600’. The east approaches consist primarily of high-level deck trusses, with a few spans of shorter steel girders entering the Westchester Landing. The existing bridge currently carries seven lanes of traffic, with a movable barrier in the middle of the bridge so that traffic can be shifted to provide 4 lanes in the predominant rush-hour direction (See Figure 2).

Figure 1 – Location map showing new bridge location (red) relative to the existing bridge (grey).



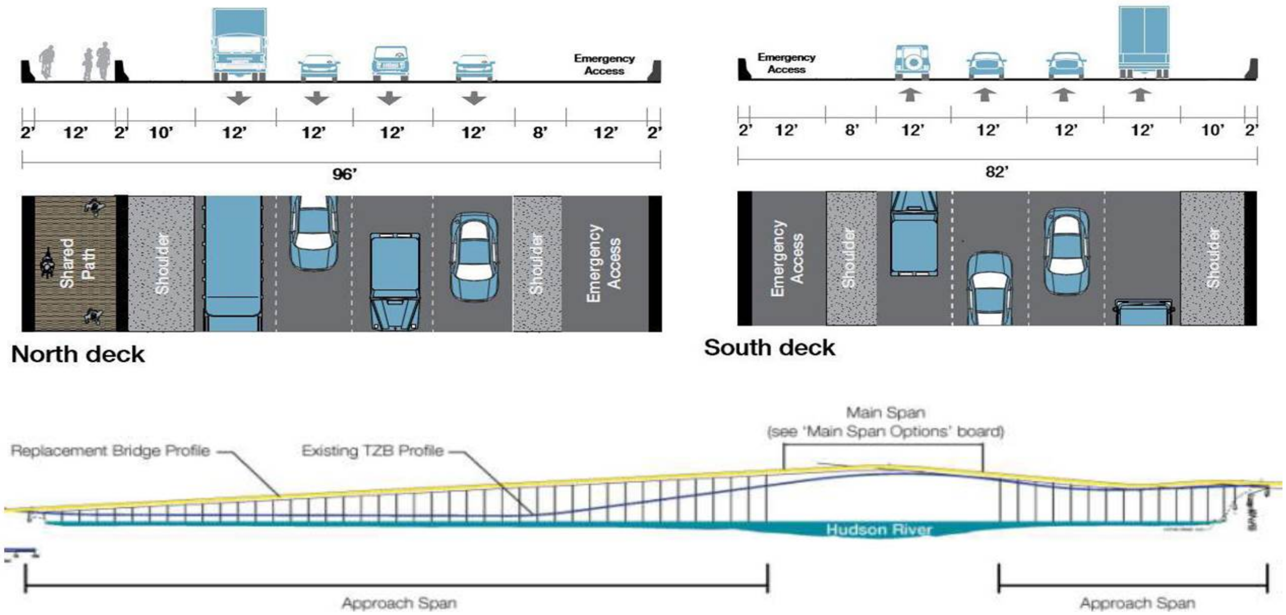
The bridge was opened in 1955 and was constructed to be as light as possible, taking into account the scarcity of material at the time following WWII and the Korean War. The western half of the bridge is over an area where bedrock is as much as 700’ below the river surface. This drove the multiple short spans on the western part of the bridge, with the piers being founded on timber piles approximately 50’ long. For the eastern half of the bridge, bedrock is 300 feet or less below the river surface, which allowed the original designer to stretch to the longer truss spans since it was possible to drive piles to rock.

Figure 2 - View of existing bridge looking east. Note barges and cranes in the river performing early construction work.

The foundation for the main span truss and several of the approach trusses are founded on floating caissons, which is a bit of a misnomer. The caissons for the main span carry about 70 percent of the total reactions through buoyancy. The caissons are supported on long piles in end bearing on rock that carry the remaining 30 percent of the load.

The New NY (Tappan Zee) Bridge will actually consist of twin uni-directional bridges. The WB bridge will carry four lanes of traffic with wide shoulders and a 12’ wide shared use path and have a total out-to out width of 96’. The EB bridge will also carry four lanes of traffic with wide shoulders and have a total out-to-out width of 87’ (See Figure 3). The WB bridge will open to traffic approximately 15 months ahead of the EB bridge and will carry eight lanes of traffic, four in each direction, until the EB bridge can be completed. The grade from the west landing up to the main span is also much flatter than for the existing bridge to allow the heavy truck traffic to better maintain speed as they travel east.

Figure 3 - General cross section of the new bridges showing location of traffic, shoulders and Shared Use Path. Elevation shows the more gradual profile for the new bridge.



Procurement Method

After spending approximately $1 billion through the 1990s to repair the Tappan Zee Bridge, the New York State Thruway Authority (TA) engaged an engineering team almost a decade ago to study alternatives to repair or replace the existing bridge. Research through inspection records showed that this high level of expenditure improved the average condition rating from about a 4 to a 5. Significant additional investment was made in the bridge in the latter part of the last decade to replace the bridge deck on the west approaches. This level of investment was not deemed to be sustainable, so the TA decided to move forward with a replacement plan.

In 2011, Governor Andrew Cuomo determined that the project was critical to the New York Metropolitan region and began to push to accelerate the project. One aspect of this acceleration was to drive legislative approval to procure projects using the design build delivery method. The TA team developed a Design Build procurement package during 2011 in anticipation of the passage of the legislation. Statements of Qualifications were accepted and shortlisting occurred in late January of 2012. Bids were accepted on July 27, 2012.

The procurement was a best value selection, meaning that the winning bid would not be based solely on price but would reflect the overall value provided by the offering. Scoring criteria were included in the bid documents, but were defined in a way that left some question as to the precise scoring criteria being used. However, the definition was adequate to guide the teams on what general areas of scoring would carry the most weight.

Three teams submitted bids and then participated in interviews with the TA team in early August of 2012. The selection of Tappan Zee Constructors (TZC), a joint venture of Fluor Enterprises, American Bridge, Traylor Brothers and Granite Construction, was officially announced in December 2012, and Notice to Proceed was given on January 18, 2013. Bid results are shown in Table 1.

Table 1 – Bid comparison showing some key areas of value that were part of the selection criteria.

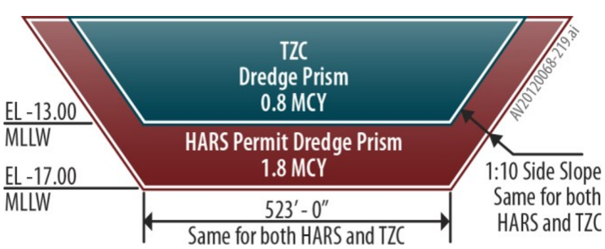
	Tappan Zee Constructors	Bechtel Tutor-Perini	Kiewit Skanska Weeks
Proposal Price	$3.142 Billion	$3.990 Billion	$4.059 Billion
Project Duration	5 Years, 2.5 Months	5 Years, 11.5 Months	5 Years, 11 Months
Dredging	951,000 cubic yds	1,800,000 cubic yds	1,550,000 cubic yds
Piles	964	1387	1392

Design Drivers

Very few specifics were provided regarding structure type in the project requirements. Aside from limiting main span structure types to either cable-stayed or tied arch structures, there were no requirements to use a specific structure type or material for the crossing. This freedom allowed the design build teams to innovate in an effort to reduce project costs. Some of the key issues that drove design decisions are discussed below.

Environmental Criteria – One of the key environmental issues that needed to be dealt with were endangered species. Great care is required to protect sturgeon in the river, which can be damaged by repeated sonic waves due to pile driving. Oyster beds were relocated away from the project site. Dredging was also an important aspect of the design, as a large volume of dredging was required to accommodate construction boats without creating significant turbidity in the river during normal construction activities (See Figure 4).

Figure 4 - Environmental benefit demonstrated by reduced dredge prism required for TZC construction.

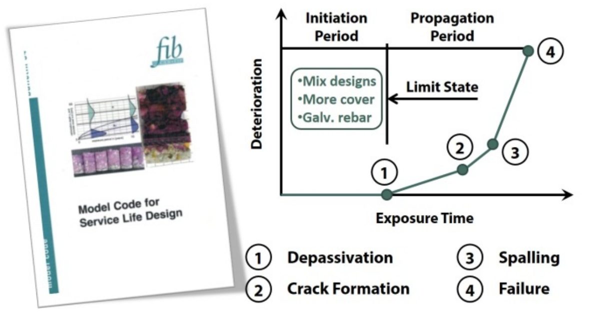


Additionally, noise, water and air quality issues were critical environmental constraints that the design builders need to deal with.

Foundation Conditions – The critical driver of the project was the foundation conditions encountered at the project site. The depth to rock was a key driver in selection of the foundation components, as was the strength of the deep clays overlaying the rock. Given the pile depths required, there is a tremendous cost associated with the pile design. As such, minimizing the superstructure and pier weights was important to minimizing the pile costs.

100-year service life requirement – The Project Requirements dictated that the major structural components of the Crossing be designed to provide a 100-year service life before major maintenance is required. The components requiring 100 year service life included the substructures, superstructures and bridge decks. Stay cables were not expected to reach this design life, reflecting that it may not be possible to provide the level of protection to the cables to reach a 100-year service life. Focusing on bridge systems that have proven long-term service life capacity was critical to the design. The Project Requirements dictated that a probabilistic approach to the service life be implemented to assure a reasonable certainty of meeting the desired service life criteria, so the team chose to use the fib-34 Model Code for Service Life Design (See Figure 5). The concrete service life design was based on the goal of reaching 100 years before depassivation occurs, leaving a significant level of service life remaining until failure. The steel design for 100 years was supported by the track record of many steel bridges that are more than 100 years old and still in service.

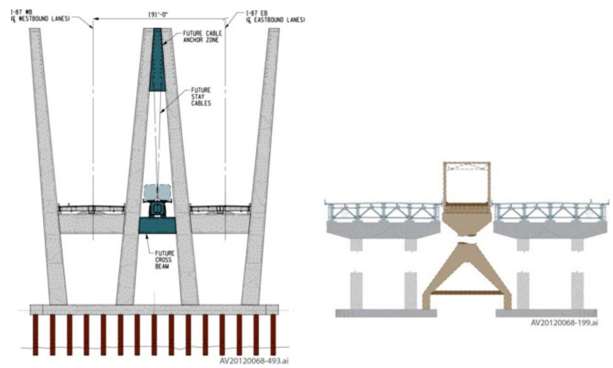
Figure 5 – Service life design based on fib-34 Model Code for Service Life Design. Design was for depassivation to occur at 100 years, not failure.



Certainty in construction methods – Certainty of construction methods was also a driver of the design. It was critical for the design build team to settle on construction materials and methods that would allow the risks to be minimized in the bid. This related to availability of materials, availability of labor, ability to modularize construction and ability to minimize changes in processes as the construction progressed. All these issues relate to pricing on bid day.

Potential Future Loading (PFL) – Designing to accommodate the possible future construction of a railroad bridge in between the two highway bridges was a significant challenge to be addressed. The highway bridge structures must be designed to accommodate the possible future construction of a rail bridge without requiring additional foundations to be constructed in the water (See Figure 6). The primary focus of this bridge is to be a transit rail structure, but the loading condition assumed is such that it would accommodate light freight as well. Developing a PFL concept that minimized the cost of current construction was a challenge for the design build teams.

Figure 6 - Potential Future Load Concept, showing how the future bridge is conceived to fit with the existing highway structure.



Aesthetics – When dealing with a major structure such as this, the sheer size of the bridge leads to some level of aesthetic. The challenge facing the design build teams was to provide an iconic bridge without adding significant cost into the design and construction. While the appearance is an important part of the design, the scoring criteria reflected a relatively low importance of this aspect in the selection criteria. Thus, the challenge for the designers was to develop an attractive design without intricacies that would significantly increase the construction cost of the Crossing. See Figures 7 and 8 below).

Figure 7 - Rendering of the new bridge viewed from Losee Park on the Westchester shore.

Figure 8 – Aerial rendering of the new bridge looking east toward the Westchester landing.

Superstructure Options Considered

The early portion of the pursuit design focused on determining the structure type that would be bid and ultimately designed and built if successful. The TA documents had anticipated both short span and long span alternatives for the approach spans. The geotechnical investigation program performed by the TA then reasonably covered the range of pier locations such that the design build teams would have a reasonable assessment of the subsurface conditions they would be dealing with in design and construction.

- Short-span Segmental – using constant depth twin box girder cross section. Spans approaching 200' were studied using precast segments erected span-by-span.
- Long-span segmental – using a balanced cantilever erection procedure. The spans were on the order of 375' in order to cut the number of piers in half, and the twin box girders would have a variable depth in order to keep the superstructure weight as low as possible.
- Steel plate girders – using short span girders on the order of 220'-240' to minimize the weight and cost of the superstructure. This option required a higher number of piers, similar to the short-span segmental option, and the high foundation costs made this option less attractive.
- Steel Girder-Substringer – using long girder spans with five main girders and four substringers. This reduces the number of piers and also reduces the overall superstructure weight through an efficient framing system.
- Steel Deck Truss – using deck trusses for the approach spans of about 450' in length. This option provided the minimum number of piers for the approach spans and the lightest superstructure.

Foundations

The Crossing will be founded primarily on a combination of 4' and 6' diameter open ended steel pipe piles, with some 3' diameter pipe piles near the shore lines where rock is closer to the water surface. There are approximately 240 – 6' diameter piles near the channel spans and approximately 750' – 4' diameter and 3' diameter piles on the remainder of the crossing. Thus, the foundations represent more a significant portion of the project cost than is typical on most bridges. This assessment became a significant driver in the overall choice of structure types, leading toward a strategy of constructing fewer foundations and minimizing the total number of piles in order to save cost and manage construction risks. Figure 9 on the next page illustrates the variable conditions encountered on the Crossing.

Steel Solution

Cable-Stayed Main Spans

The Project Requirements permitted consideration of either a cable-stayed or tied arch main span. The TZC team chose to design and construct a composite cable-stayed bridge for the main channel spans. This is a twin-tower cable-stayed bridge, with modified H-shaped towers (See Figure 10). The main channel span is 1200' in length, with anchor spans of 515' each. The tower legs slope outward and have no crossbeam above the deck level, which will help to expedite the construction schedule. The cable anchorages bolt to the outside of the I-shaped steel edge girders (See Figure 11).

Figure 9 – Subsurface soil profile at the bridge site showing the high level of variation in foundation conditions.

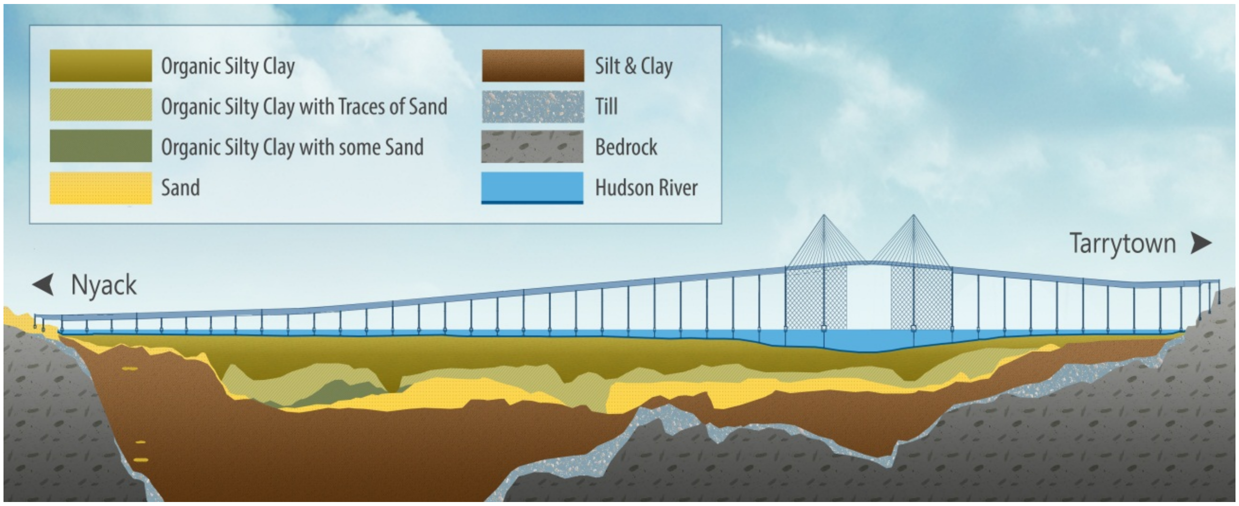


Figure 10 - Plan and Elevation of the three-span cable-stayed unit.

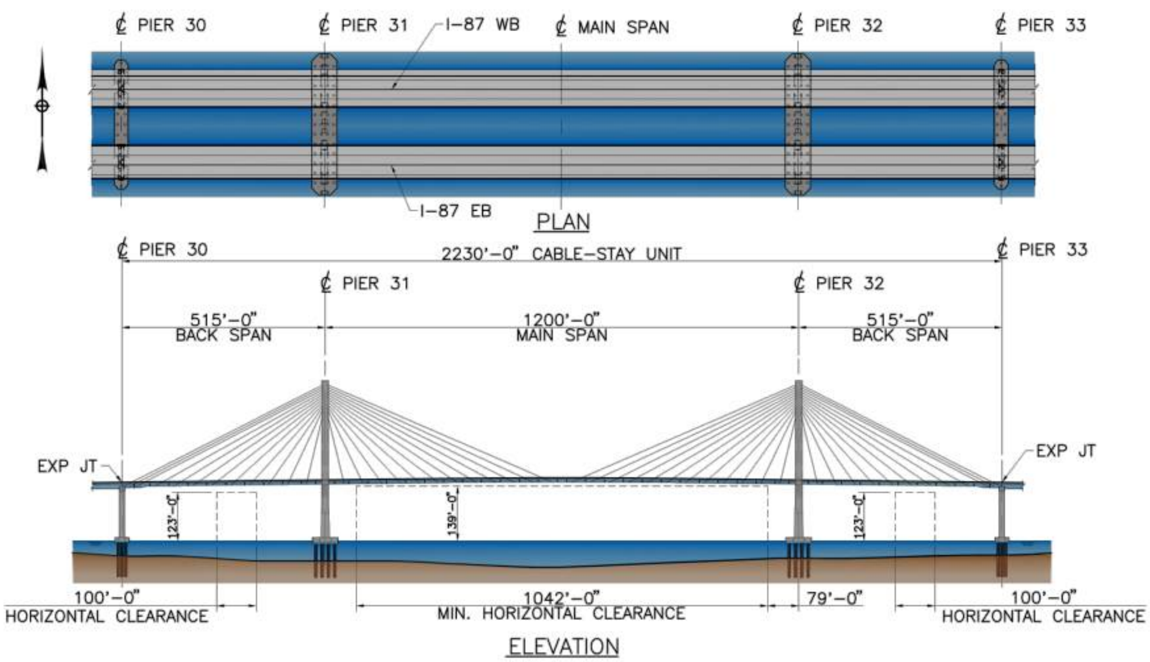
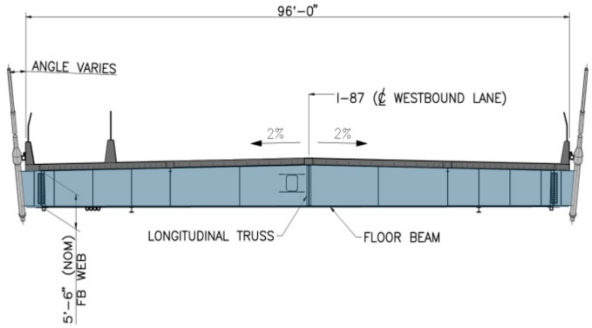


Figure 11 - Deck cross section of the cable-stayed unit. Note the outward cant of the stay cables and the anchorage connected to the outside of the edge girders



The outward cant of the towers and cables takes advantage of gravity to provide stability above the deck, allowing the elimination of the above deck strut.

The floor system is a relatively simple system of transverse floorbeams spaced on 16' centers with longitudinal stringers (support struts) to support the precast deck panels between floorbeams (See Figure 12). These stringers provide a convenient location to construct closure pours between the precast panels as the bridge erection progresses. There is also a stiffening truss near the center of each bridge to provide an extra level of redundancy in the superstructure.

A significant advantage to the composite cable-stayed structure as opposed to a concrete superstructure is the significant weight reduction associated with the steel superstructure. This allows the balanced cantilever construction to be accomplished with smaller cranes while also reducing the size of stay cables required to support the superstructure. This also translates to some savings in the foundations for the main spans.

Steel Deck Girder Approach Spans

A girder-substringer framing system was chosen for the approach spans (See Figure 13). This type of system typically has provided a savings of between 10 and 20 percent when compared to a multi-girder system, and is significantly lighter than any of the concrete alternates studied. This weight savings was particularly important for the approach spans, as approximately half of the approach spans are supported on friction piles.

The girder-substringer system also provides significant savings in fabrication over a multi-girder system. The design provides five deep girders in the cross section, with four rolled beam substringers. Had a multi-girder system been chosen, there would have been either seven or eight girders in the overall cross section, requiring significantly more girder fabrication. Additionally, the number of crossframes required would have increased accordingly. Given the relative fabrication cost of crossframes, this also provided a significant savings to the team.

Another advantage to the framing system was realized by TZC. Given the amount of work that will be self-performed by the team and the size of equipment available to the team, much of this bridge will be constructed in a modular manner. The approach superstructures will be erected in two or three girder groups a span at a time, ratherthan the more conventional stick erection from splice to splice. This will eliminate almost all temporary falsework in the river, providing a significant savings in both time and construction operations on the water.

Precast Deck Panels

The cable-stayed spans used precast panels for the bridge decks. The panels have transverse cast-in-place joints at every floorbeam and longitudinal joints at the stringer locations. There is a cast-in-place section of slab directly over the edge girders that also serves to anchor the fascia barriers. A majority of the deck ultimately is in compression due to the loads introduced by the stay cables. There is a portion of the deck near the center of the main span that is between the stay cables that is longitudinally post-tensioned to avoid future deck cracking in this area.

The approach units are also constructed using precast deck panels, although the system functions somewhat differently. The typical approach panels are 12' long and 45'-50' wide, and there is a single longitudinal closure pour between panels. The panels are reinforced by mild reinforcement, with heavy through reinforcement in the transverse joints. The key design parameter for the panel reinforcement was to limit reinforcement stresses to a level such that crack widths are limited to 0.012" at 2" cover on the top reinforcement steel.

Figure 12 - Half plan and elevation showing the framing layout for the floor system.

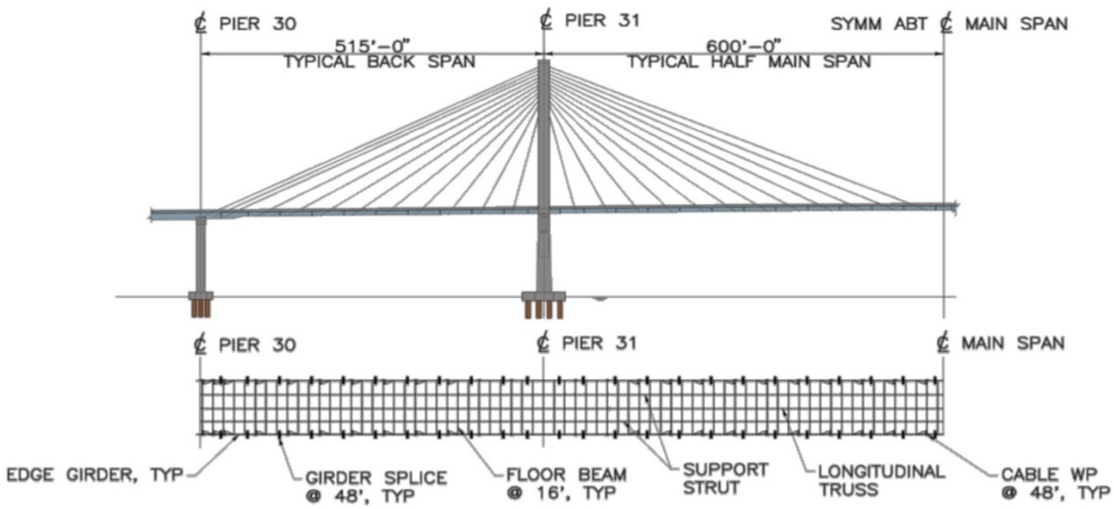
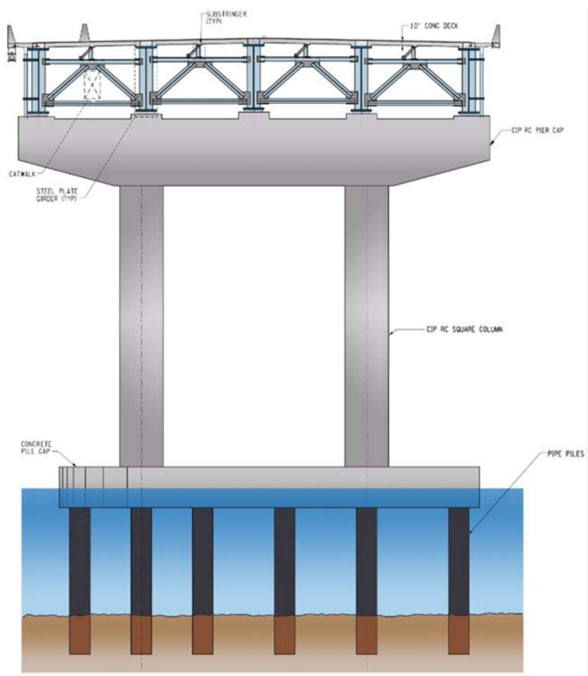


Figure 13 - Typical approach span cross section at a pier. Note that the pile caps are at water level and not in contact with the ground



The superstructure was analyzed for longitudinal stresses in the deck from superimposed dead load and live load, as well as including the effects of shrinkage in the slab. This results in more than the 1% reinforcement steel that is traditionally placed in cast-in-place concrete decks in the negative moment regions.

The approach of limiting crack width to 0.012" is one aspect of achieving a 100 year service life for all concrete components of the bridge. For the bridge decks, the contract also requires that a polyester concrete overlay be included as part of the deck system. This overlay is assumed to be replaced every 30 years at a maximum to help protect the based panels from the heavy use of de-icing salts.

Special Structure Details

As part of the public involvement and visual quality processes, the project requirements include the incorporation of a shared use path (SUP) for pedestrians and bicycles as part of the permanent westbound bridge configuration. In addition, one of the intermediate construction stages include a period of time where westbound vehicular traffic is allowed to utilize the future SUP portion of the cross-section as a travel lane.

Belvederes – the westbound bridge incorporates six 12 ft x 60 ft belvedere structures cantilevered from the north face of the exterior girders. These belvederes will form scenic overlook areas where the public will be able to pause and admire the scenic Hudson River Valley (See Figure 14). Each of the belvederes will feature a different aesthetic theme as established through a series of public visual quality charettes. The belvedere structures will be supported through a cantilever connection from the exterior girder web and rigidly braced to the interior girder to eliminate torsional girder deformations.

Permanent crossovers – will be provided between the eastbound and westbound structures to facilitate public evacuation and turnaround capabilities in the event of an extended traffic obstruction. These structures will consist of a simply-supported span supported on brackets attached to the interior girders.

Figure 14 - Rendering of the proposal concept for the belvederes located intermittently across the Crossing.

These structures add additional dead load and live load cases which were considered during the design. Pier 37 was particularly affected by these loads as it supports both a belvedere and a crossover span which greatly increased the foundation size and number of piles at this location.

Special Details Driven by Contractors

One of the great benefits of design build is that the designer can interact with the builder and come up with a design that meets all the design criteria in a way that is cost-effective for the builder to build. While not all design build teams work this well together, the TZC Team has exhibited a great depth of interaction to assure that the designs are efficient for TZC to build.

In that light, there were several aspects of the girder designs that were driven by TZC. Among the general details were:

- Maximum total girder depth of 12' – this limit was imposed to avoid extra shipping costs associated with oversized girders.
- Maximum shipping length of 120' – this limit was also imposed to avoid excessive shipping costs
- Maximum piece weight limited to 100 tons – this weight limit was driven by limitations on both shop equipment capacities and shipping
- Unstiffened girder webs – this approach was taken to accomplish two critical things. The first goal was to reduce the amount of fabrication required. Very often, girder webs this deep are not only transversely stiffened but longitudinally stiffened. The cost of longitudinal and transverse stiffeners is generally much higher than is the cost of the additional steel that is included for deep girders. The second goal was to reduce the number of stress risers on the girders, which is an effective strategy when driving to achieve a 100-year service life before major maintenance is required. A side benefit of this is that, as welded girder attachments are eliminated, the level of effort that is required for bridge inspections is reduced.
- Hybrid girders – the girder flanges are a mixture of Grade 50W and HPS 70W flange plates. This was done to reduce girder weight where possible, while balancing the weight savings with the premium charged for HPS 70W steel. There is an added benefit that the HPS 70W flange plates have an extremely high fracture toughness, which supports the project goal of 100 year service life before major maintenance. The balance that needed to be reached was to use HPS 70W appropriately while not placing too much of a strain on the limited supply chain for HPS 70W steel.

There were several other aspects of the approach girder designs that drove certain design decisions that were not directly related to girder fabrication issues. Issues of interest include:

- Use of A490 bolts for girder field splices – The primary benefits were to minimize the length of the field splice plates in order to keep the bolted connections as efficient as possible. On the cable-stayed edge girders, an additional benefit of shortening the edge girder splice plates is to avoid interferences between the edge girder splices and the bolted cable anchorages.

- Top surface of top flange remains in consistent plane – this detail was incorporated to accommodate the precast deck panels as simply as possible. This was accomplished by varying the web depths of the girder flanges on the approach spans. Girder web depths are transitioned only at the bolted field splice locations (See Figure 15 on the next page).
- Top flange splice plates on the approach girders narrower than the flanges – this detail was incorporated to accommodate the bedding strips for the precast deck panels that will also function as the side forms for the girder haunches.

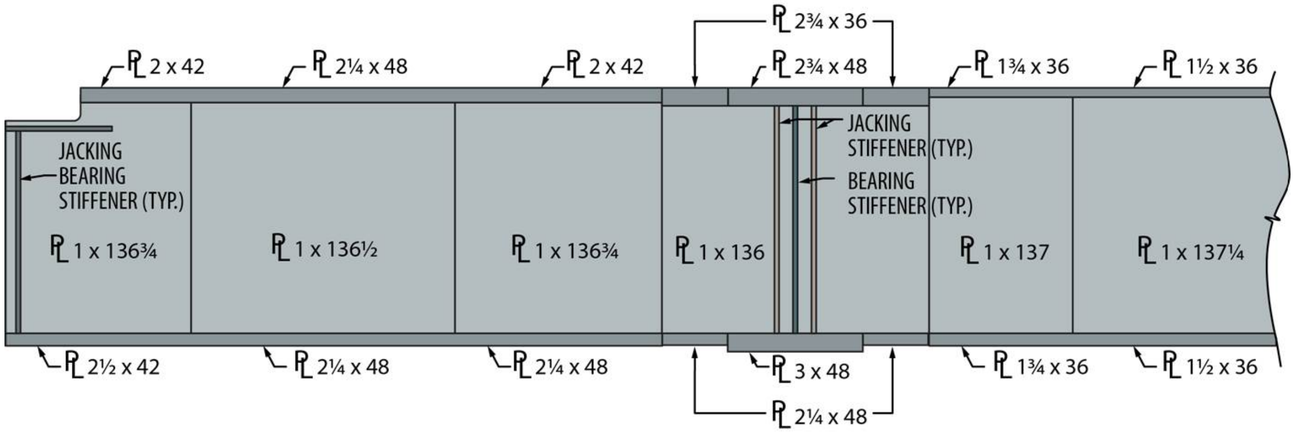
Planned Construction of the Approach Spans

Given the logistical challenges of girder erection on the water, TZC looked for strategies to manage these challenges. Construction on the water requires many workers to be transported out to the locations of the work. Additionally, the safety risks of construction on the water are much higher in a marine environment than they are on land. The site is also very windy, which creates additional safety concerns.

As a result, TZC decided to take advantage of the large equipment that they have available to them to modularize the construction to the greatest extent possible as a strategy to manage the marine construction risks. Three key ways that this will be accomplished are as follows:

- Precast Pile Cap Tubs – the water line pile caps for a majority of the approach piers will use ‘precast floating forms’ for the pile cap construction. These caps will be made composite with the infill concrete. This reduces the risks, construction time and environmental impacts associated with conventional cofferdams.
- Precast Pier Caps – Many of the approach span pier caps will be constructed using precast forms that can be set on top of the pier columns. The forms will be prestressed to obtain a target stress level at the point of which the infill is completed, with mild reinforcement designed to carry the remaining load. This also reduces the number of workers that will need to be out on the water to place the pier caps.
- Modular construction of the approach span frames – girders for the approach spans will be erected in pairs or triples, diaphragmmed together prior to lifting. The girders will be lifted a span at a time, which will minimize the need for temporary falsework for the approach span erection. One aspect of this approach is that the two and three girder frames will be assembled at an off-site assembly yard and then barged out to the bridge site. Again, this allows most of the assembly work to be completed on land as opposed to high in the air over the water, improving safety significantly.
- Steel girders designed to carry all slab loads in the non-composite state – this approach gives the contractors the option to place all deck panels within a multi-span unit at any time during the calendar year. TZC can then come back at their convenience to complete the closure pours to make the panels composite with the girders. No formwork for the closure pours will be required, thus reducing work on the water, improving safety and avoiding issues of access for these operations.
- The easternmost unit on the westbound bridge is planned to be incrementally launched into position. This will avoid crane capacity issues over the Metro North Railroad tracks, as MNR requires cranes to have a capacity of at least 150% of the weight of any pick over the tracks. The launching will allow the girders to be erected in a safe manner while minimizing the risk of erection over the MNR. Limited horizontal space at the east end of

Figure 15 - Partial girder elevation showing the modified top flange details to accommodate precast deck panels.



the approach roadway prevents full assembly of the 9-girder cross-section prior to launching. Therefore, the girders will be launched as three 3-girder subassemblies, the first two of which will be slid laterally into their correct final position after launching. Crossframes will then be installed between the subassemblies after sliding is complete.

Interesting Facts

- The current Tappan Zee Bridge carries nearly 140,000 vehicles per day, with a toll for cars of only $5.
- Approximately 20% of the entire toll revenue of the Thruway is collected on this bridge.
- The annual capital budget for the Thruway is approximately $250 million, less than 10% of the cost of this project.
- The existing bridge was completed in 1955. A fender system to protect the floating caisson foundations adjacent to the shipping channel was installed in the late 1990s.
- The new superstructures for the bridges will contain about 100,000 tons of fabricated structural steel.
- The piles for the new bridge contain approximately 80,000 tons of additional steel.
- This is the largest single design build transportation project to date in the US. It will also receive the largest TIFIA loan granted to date for a transportation project.

Summary

The New NY (Tappan Zee) Bridge project is a great example of how the design build method of project delivery can lead to innovation and cost-effective project delivery. The design build team worked together during the bid phase to vet various structural systems, ultimately developing a cost-effective to design and build an iconic bridge for the New York area.

The advantages of structural steel were made evident on this project. The relatively light superstructure allowed the TZC team to minimize the foundation costs. The ability to erect large portions of the steel framing directly from barges reduces risk for TZC.

Additionally, the ability to modify details of the steel to accommodate specific needs of the project, such as the precast deck panels, allowed TZC to optimize their construction operations to provide a cost-effective design while giving them the ability to manage construction and supply risks effectively