THE GOETHALS BRIDGE REPLACEMENT PROJECT

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BIOGRAPHY

Seth Condell is a structural engineer specializing in the design, rehabilitation, and inspection of long-span and complex bridge structures since 1998.

Mr. Condell has held key roles in the design of the new Tacoma Narrows Suspension Bridge, the new Autoroute 25 Cable-Stayed Bridge in Montreal, Quebec and the new Fore River Lift Bridge in Massachusetts. Mr. Condell has also held key roles in the construction engineering of the Lions Gate Bridge and as a designer for the Carquinez Suspension Bridge near San Francisco, California.

Mr. Condell is currently the Design Manager for the Goethals Bridge Replacement Project, connecting New York and New Jersey., overseeing the design and Engineering Services During Construction for this $935M project. The crossing consists of a 7,306.5 ft long dual span, a railroad bridge replacement, utility upgrades, low level stream crossing, on-bridge utilities, the realignment of a local street in New York, and access roads on both sides of the Arthur Kill.

SUMMARY

The Port Authority of New York and New Jersey is replacing the 1928 Goethals Bridge. The replacement crossing will be a, state-of-the-art dual-span cable-stayed structure connecting Elizabeth, New Jersey and Staten Island, NY. Crossing the Arthur Kill with a 900 ft main span. Including sidespans, each cable-stayed span boasts a total of 1,635 ft of suspended deck. The cable stayed main bridge is, however, only a portion of the overall project.

The project will be constructed under a Public Private Partnership (P3) with a 35 year concession period.

The towers of the dual-span bridge structure together form a "double V" configuration. This configuration was selected such that the stay cables diverge from the roadway, providing both an "open" driving experience and an aesthetically pleasing form that fits the context of the surrounding area. The superstructure of the cable-stayed spans will feature a patent pending structural framing system that provides a unique level of redundancy and improved overall structural resiliency.

THE GOETHALS BRIDGE REPLACEMENT PROJECT

Introduction and Site History

The site of the Goethals Bridge Replacement Project is no stranger to historic crossings. While a ferry crossing at the site that helped to establish Staten Island as an important link in the overland stage coach route between Philadelphia and New York can be traced back to the 1690's, the first span across the Arthur Kill (a 10 mile long river channel between Staten Island, NY and Elizabeth, New Jersey) would not be erected until the American Revolution. At the site of the current crossing, British troops erected a pontoon bridge which was short-lived as the crossing was subsequently destroyed by the same troops to slow the advance of the Continental Army after the American victory at the Battle of Springfield later that year.

The Kill would not be spanned again for over 100 years, until 1890, when the Baltimore and Ohio Railroad erected the Arthur Kill Bridge - a swing bridge at the site that boasted the world's longest swing span at 500 ft. (This swing bridge remained in service until 1959 when the Arthur Kill Vertical Lift Bridge was opened nearby. This bridge holds the world record for longest lift span at 558 feet.)

In response to growing congestion of the ferry system, economic development of Staten Island, and the rise of the automobile, the New York Port Authority, formed in 1921 (later the Port Authority of New York and New Jersey), commissioned the study of, and later the construction of a vehicular crossing at the site. Designed by Alexander Waddel, one of the nation's preeminent bridge engineers of his day, the Goethals bridge is in fact named after the Port Authority's first Consulting Engineer, George Washington Goethals of Panama Canal fame. Opening in 1928, the Goethals Bridge became the first of three vehicular crossings that link Staten Island, one of the five boroughs of New York City, to New Jersey[1].

Project Overview

Having provided almost 90 years of reliable service, the existing Goethals Bridge was designed and built to standards from the dawn of the age of the automobile. With current traffic volumes and future projects, the crossing is functionally obsolete. The bridge features substandard 10-foot-wide lanes – two in each direction – and no shoulders, which presents a safety concern for trucks and large vehicles. Situated on Interstate 278, the current crossing is a source of peak hour congestion.

The Port Authority of New York and New Jersey ("The Authority") has thus undertaken the current replacement project to remove this choke point in the region's transportation network and also has strategically timed the replacement to avoid costly repairs over the next decades if the existing bridge were to remain in place.

The replacement crossing will be a dual span, state-of-the-art cable-stayed structure connecting Elizabeth, New Jersey and Staten Island, NY. (See Figure 1.) Crossing the Arthur Kill with a 900 ft main span, the new bridge will provide a significant navigational improvement over the current 672 ft horizontal clearance for marine traffic. Including sidespans, each cable-stayed span boasts a total of 1,635 ft of suspended deck. The cable stayed bridge is, however, only a portion of the overall project. The project in its entirety includes over 7,300 feet of elevated mainline structure in each direction, a new railroad bridge west of the New York toll plaza, a maintenance and control facility for the Developer, and an access road through the swamp land on the New York side to facilitate maintenance and inspection, including its own low-level crossing of Old Place Creek.

The project is being constructed under a Public Private Partnership lead by Macquarie Infrastructure, who will finance the bridge construction and maintenance for the 35 year concession period. The lead contractor is a joint venture between Kiewit Corporation, Weeks

[1] While the Goethals Bridge is in fact the first of the three Crossings, Goethals, Outerbridge and Bayonne, it is an interesting historical footnote that the ceremonial ribbon cutting party drove directly from the ceremony at the Goethals Bridge to a similar ceremony at the Outerbridge Crossing later that same day. It is also of interest to note that despite common misconception, the Outerbridge Crossing is not so named because it is the outermost of the three Staten Island Bridges, but in fact named after the first Commissioner of the New York Port Authority, Eugenius H. Outerbridge.

Marine, and Massman Construction Company, (KWM) with design services by Parsons.

The new crossing will be constructed to the south of the existing bridge and will feature three 12 foot wide eastbound and three 12 foot wide westbound lanes, with full shoulders and a shared use / bicycle-pedestrian path on the westbound bridge. Additionally, the bridge was designed for a future transit corridor between the structures.

Recognizing the significant investment, the Authority has prescribed the main components of the structure to provide an extended service life, with the design team tasked to demonstrate that major components provide up to 150 years of reliable service before a major rehabilitation event.

The following paper will focus on the cable stayed bridge.

Cable Stayed Bridge Configuration

The bridge consists of a 900’-0” main span, two 367’-6” back spans, a 190’-0” west flanking span, and a 157’-6” east flanking span. See Figure 2. Both the eastbound and westbound structures will carry three 12 foot wide lanes with full shoulders – a vast improvement over the existing structure.

The main towers are configured as a double “V” in elevation, with each “V” supporting independent structures. To comply with a project requirement prohibiting vertical tower legs, the team configured the tower legs with a 5 degree outward lean. See Figure 5. With the open V shaped towers and the outward lean of the stay cables, all cable and structure above the roadway has been eliminated, and the hazard of ice falling from these components onto passing cars has been minimized. Applying a philosophy of designing safety into a project, this configuration was deemed important by the design team, as falling

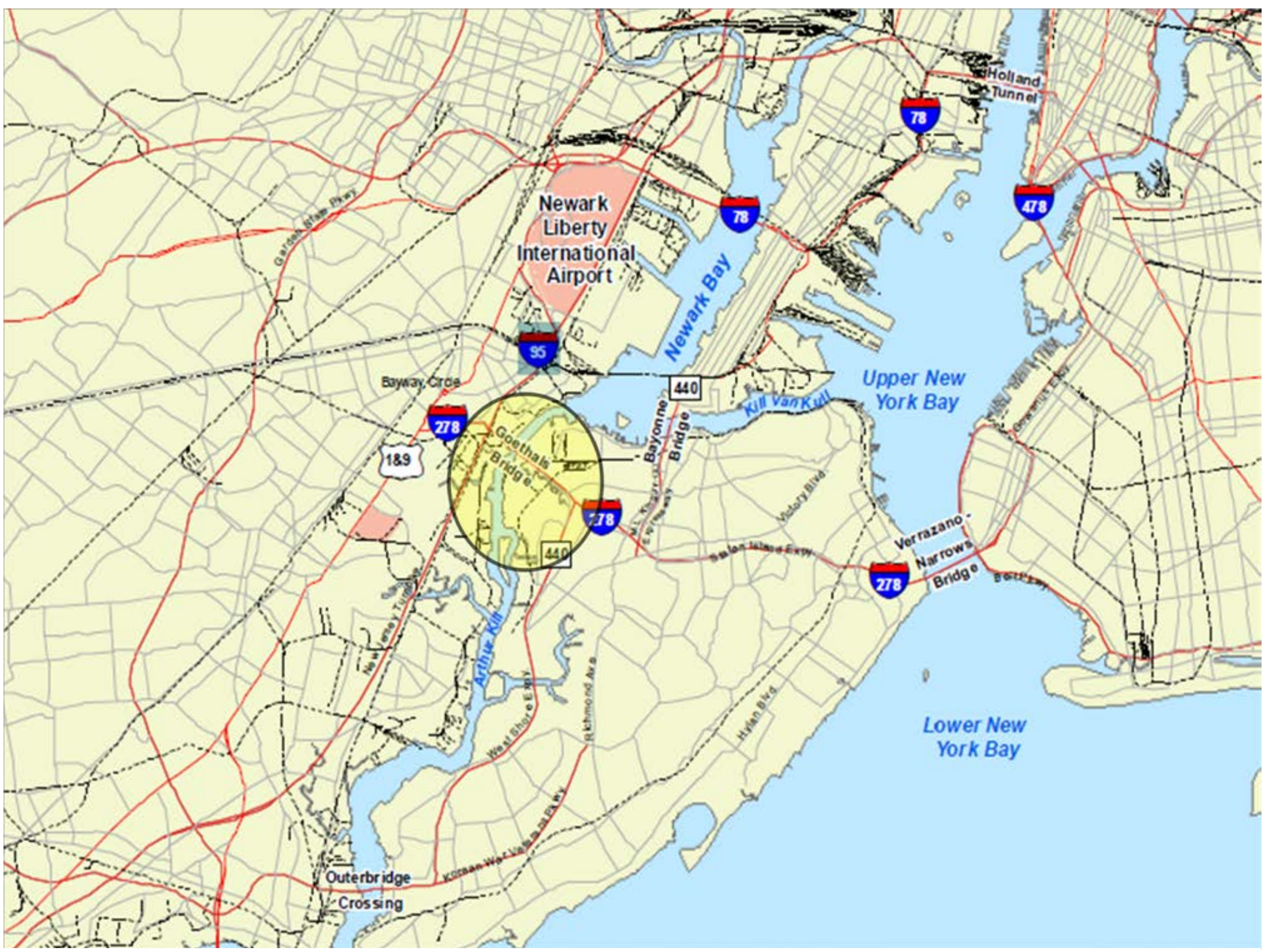

Figure 1: Site Location Map

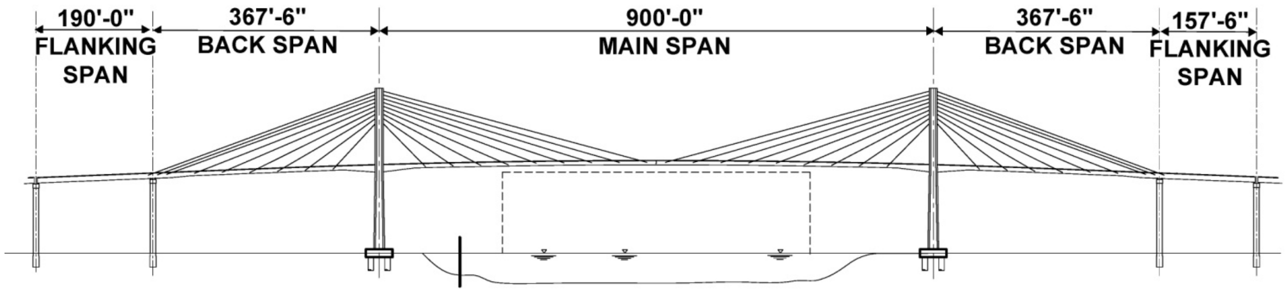

Figure 2: Main Bridge Configuration. Note Shallow Stay Cable Angles.

ice has plagued other crossings in the region.

Strict Service Life requirements are being applied to the project to ensure the new crossing serves the public for many years to come. Specifically, non replaceable components such as the towers and foundations are being designed for a service life of not less than 150 years. For replaceable components, a defined level of remaining service life has been identified as a part and parcel to the hand back conditions that NYNJ Link must provide at the end of the concession agreement when the facility is turned over to the PANYNJ in full.

Deck System

For the cable stayed spans, the deck consists of full depth, lightweight precast concrete panels, made continuous by way of concrete closure pours over the floorbeams, edge girders, and between panels. The deck panels are then provided with a polyester polymer concrete overlay. The closure pours serve also to make the deck composite with the structural steel framing system. Near center span and adjacent to the anchor piers, the deck will be post-tensioned longitudinally to preclude tension in the top fiber of concrete. Elsewhere the deck is precompressed entirely by the thrust of the stay cables and the overall structural system. Elimination of microcracking in the concrete top fiber serves as a line of defense against chloride intrusion that can lead to corrosion of the reinforcement, followed by premature failure of the concrete. Additionally, the deck is provided with an overlay of impermeable polyester polymer concrete (PPC). And for a final measure against premature degradation, the bar reinforcement is specified to be stainless steel.

Directly supporting the concrete deck is a steel framing system consisting of longitudinal steel edge girders, transverse floorbeams spaced at 15-ft, and two longitudinal redundancy trusses.

Project specific live loading ensures resiliency of the deck under the punishment of heavily laden traffic. Resulting from Weigh-in-Motion studies specific to the New York City area, a modified HL-93 loading consisting of a 15kip front axle and five 29 kip trailing axles was developed for the project and included in the criteria for deck design. See Figure 3.

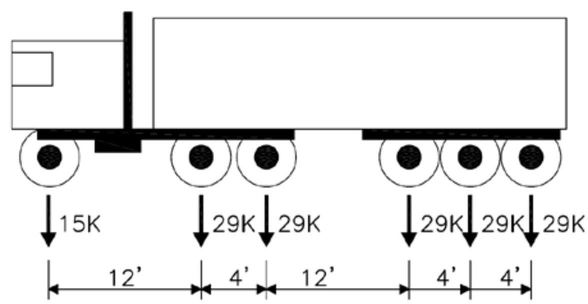

Figure 3: Project Specific Live Load Truck

Redundancy Truss

Steel and concrete cable stayed superstructure systems often make use of fabricated steel edge girders along each cable plane to serve as primary load carrying elements. See Figure 4. While this type of system is sufficient for carrying service loads and even most extreme event loads, the floorbeams spanning between the girders are typically classified as fracture critical members, as the loss of one floorbeam overloads adjacent floorbeams and the edge girder, likely compromising structural integrity. For the Goethals Bridge Replacement, the design team devised an innovative use of materials to eliminate this fracture critical scenario and introduce redundancy.

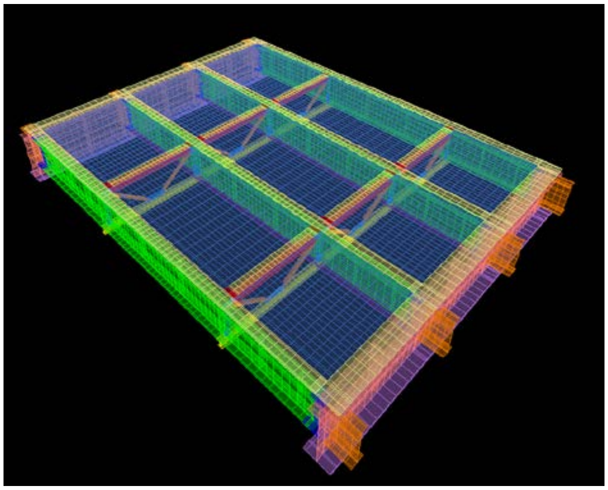

Figure 4: Overall layout of deck framing. Note redundancy trusses parallel to edge girders.

As per project requirements, the cable stayed bridge is to be provided with maintenance travelers supported by rails running the full length of the cable supported spans. Also running the full length of the cable supported spans are deck panel support beams used as forms below the closure pours between panels. By connecting these otherwise single-use components into a longitudinal truss, a redundant load path is established in what might otherwise be a compromised structural system should a floorbeam or edge girder be damaged.

In addition, by providing an alternate load path, the floorbeams need not be classified as fracture critical members (FCM), allowing for fabrication conforming to customary structural steel fabrication requirements and not invoking the additional stringent material and fabrication provisions of fracture critical steel elements. Nonetheless, in accordance with owner-prescribed requirements, the floorbeams will be classified as structural redundant members in a manner comparable to a June 20, 2012 FHWA memo entitled "Clarification of Requirements for Fracture Critical Members", wherein a new classification of member was introduced, a "Structural Redundant Member", or SRM. While the annual inspection requirements of a FCM need not be applied to an SRM, FCM fabrication requirements still apply.

Figure 5: Rendering of Completed Span

Deck Level Stay Anchors

Selecting a system to anchor the cable stays at deck level is a defining design decision for any cable stayed bridge. For the Goethals project, the stay anchors were configured to be side-mounted to the outboard face of the edge girder. In this way each stay anchor pipe is framed into the girders at floorbeam locations to provide a rigid load path for all force effects. This system has several advantages. The configuration aligns the edge girder inboard of the stay cables and thus reduces the span of floorbeams, thereby reducing the associated steel quantities. Additionally, the edge girder alignment conveniently accommodates direct fixation of the edge girders to the towers thereby introducing a straightforward structural system absent of bearings or damping devices. Pier table construction is also simplified overall. With this configuration, the plane of the stays is protected by an offset distance with respect to passing traffic, salt laden road spray and objects kicked up by passing traffic. Finally, locating the stay anchor outboard of the girder accommodates stay stressing at the deck level, allowing for a thinner, sleeker tower top since it is not necessary to introduce a stressing chamber within the tower.

Stay System Configuration and Anchor Boxes

Overall, the stay system for the Goethals Bridge consists of standard stay cable components. Unique to the project, however, is the global configuration of the stay cables. Due to the project proximity to Newark Liberty International Airport, Federal Aviation Administration rulings limit the height of the towers to of a mere 268.51 feet, or 121.82 feet above the deck level. This translates to a minimum stay cable angle at the center of the bridge of 15 degrees – well below a typical minimum angle of 23 degrees +/-. The result is larger than otherwise expected stay cable sizes and preloading in order to achieve the necessary structural performance for vehicle and wind loads. Also, following from this shallow stay angle, wind tunnel testing found the bridge susceptible to vortex induced oscillations that were mitigated by use of a partially open TL-5 roadway barrier and fairings in the center two thirds of the leading edges of the main span.

Mitigation of the shallow stay angles began, however, at the overall configuration of the stay system. Every effort was made to reduce the stay-to-stay height in the tower to maximize stay angles wherever possible – including the development of a new configuration of anchor box.

Traditionally cable stayed bridges have been built using a handful of different options regarding stay cable anchor systems within the tower tops. These include direct bearing of the stay cable anchor heads on the interior face of a hollow tower leg. In this case the walls of the tower leg are most often post tensioned to withstand the splitting force of the opposing cables. Alternatively, steel anchor boxes have been used. These most often include a transverse strongback-beam or a longitudinal tie-beam that sheds the stay anchor load to a steel core within the tower leg. Others have used saddle type systems whereby the cables pass through the tower tops eliminating the need for fixed anchorages and stay cable terminations – an option deemed inappropriate for the Goethals configuration.

The design team considered all of the above options following a systematic study that included compatibility and risk related to intended erection methods, efficiencies in accommodating future transit upsizing of strands, overall complexity of the respective solutions and opportunities for cost competitiveness. In this regard, the saddle solution was determined to be overall an efficient and relatively simple solution. However, the potential of strands slipping during specific bridge erection stages or during an extreme event was found to be an unacceptable risk, or at a very minimum a constraining parameter of the design, and thus this solution was not considered further.

Initially, the anchor box solution was advanced incorporating customary strongback-beams. However, largely due to the need to accommodate future transit stay upsizing, these beams became exceedingly large and encroached significantly on the working space for strand installation. For this reason, the design team sought to develop a more efficient system that would, at a minimum, eliminate the need of bulky bending elements such as the strongback beams.

An innovative anchor box system was developed such that each stay cable anchor head would be received by a custom fabricated anchor pipe that is inclusive of an integral bearing ring at the loaded end of the pipe. See Figure 6. Also integral to each anchor pipe are four radial fin-plates that serve to shed the load from the pipe to a surrounding steel box that has an arching form with efficiencies similar to a saddle. Anchor pipes are secured to each end of the individual box and each opposing pair of stay cables has its own unique anchor box that will be completely encased in the reinforced tower leg, but for the front face of the box that is provided with access cut-outs for servicing the strand anchors during construction. Continuity with the concrete tower leg interface is achieved with conventional shear studs.

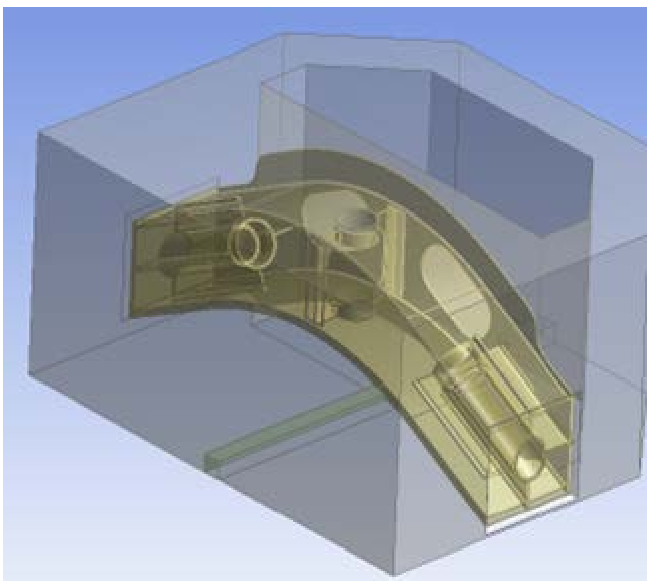

Figure 6: Stay Cable Anchor Box at Tower Top

The efficiency of this unique anchor box system is achieved primarily by the direct load path from the anchor pipe to the fin-plates and then from the fin plates to the box side walls. This is accomplished in a relatively small space and through shear transfer within the fins rather than bending of strongback beams spanning the full width of the tower interior chamber. The integral bearing ring serves to receive the pressure load from the strand anchor plate in a customary manner, and also serves to buttress the pipe from radial deformation at the ends of each fin plate. In addition to the overall structural efficiency of the system, it has the additional benefit of being quite compact compared to the customary anchor box and this can accommodate the future transit cable upsizing without the need to increase the tower leg proportions for the future configuration.

Anchor Piers and Flanking Spans

To counter balance the main span, a triple set of backstay cables diverge from the tower top and anchor side-by-side to the edge girder at Pier No. 2, i.e. the anchor pier. On past designs mechanical systems such as rocker links or bearings secure the edge girders in the vicinity of the backstay cable anchorages. However, for the new Goethals Bridge a unique feature of the approach span piers lends an opportunity for simplicity and efficiency.

To achieve the necessary river navigation clearance, the approach spans rise at a grade of four percent to meet the cable stayed bridge. This results in Pier No. 2 at the above noted anchor cables being 126 feet tall. This height, combined with pier shafts that are integral extensions of the drilled shaft foundations, results in a flexible substructure along the centerline of the bridge. This feature was used to the advantage of the overall structural system in that the edge girders are fixed to the pier caps and the inherent flexibility eliminates the need for mechanical bearings of any type. To resist the upward pull of the anchor cables, a 1,240,000 lbs. concrete counterweight is introduced between the edge girders and is integral with the pier cap.

Further efficiencies were achieved by introducing the flanking spans by continuing the edge girders one more span to Pier No. 3. This configuration allows for structural efficiencies by way of continuity of the edge girders, and due to the fact that the reaction of the flanking span girders at Pier No. 2 helps counter the upward pull of the triple backstay cables. The flanking span also includes two interior girders and a substringer framing system that terminates at the counterweight. Considering the continuity of the superstructure framing at Pier No. 2, integration of the counterweight into the pier substructure, and the efficient use of flexible shaft and column foundations, this potentially complex transition from the cable stayed spans to the approach spans has been made simple and durable by way of overall integration of virtually every bridge element at that location.

Extended Service Life

To ensure the new structure provides exemplary service for future generations, the Authority has specified major components to provide an extended service life:

Component	Service Life (years)
Foundation Elements	150
Substructure Elements	150
Cable Systems	100
Steel Edge Girders and Floorbeams	100
Prestressed Concrete Girders	100
Deck Slabs	100
Bearings	50

Complex methods were used to validate the required service life, inclusive of chloride penetration modeling of concrete, extensive permeability testing, materials selection, use of sealers/membranes, careful selection of paint systems, and a detailed maintenance and operations plan, all of which was captured in a project-specific corrosion protection plan.

Future Transit

The project requirements mandate that the project include provisions for expansion in the form of a mass transit corridor. This corridor must meet the needs of either a dual light rail transit (LRT) system or a transit roadway, whichever controls the initial-build design. In this way the design of the initial-build must accommodate the Ultimate Configuration without the need to strengthen the towers, tower foundations, or superstructure. Cable anchors also need to accommodate the future transit load, though not all cable strands need to be installed at the time of initial-build.

In addition to the service loads prescribed for the future transit, the Initial Configuratino needed to accommodate seismic and extreme event wind loads applicable for the Ultimate Configuration.

Resulting from a dual-span bridge, the addition of the future transit is straightforward. Overall, the concept considers that new steel framing will be added to connect the two interior edge girders of the dual-span cable stayed bridge. Each of the new floorbeams will be framed at the location of the existing floorbeams on the Eastbound and Westbound structures every third floorbeam, which is also a stay cable anchor point.

Once the new floorbeams are erected, stringers and a deck system can be constructed for the transit roadway, this being the heavier and controlling design vs. the dual tracks of LRT. Of course as the framing and deck components are erected, additional strands will supplement the initial-build stay cables. However, as indicated above, all of the stay cable anchor systems are already designed to receive the added strands and load imposed. In this way the new strands are to be installed and stressed in order to maintain the initial-build bridge profile as the future transit corridor becomes reality.

Ship Collision

The new Goethals Bridge will span the Arthur Kill Channel between Staten Island, New York and Elizabeth, New Jersey. The channel is a stretch of the Arthur Kill waterway connecting the Lower New York Bay with the Upper New York Bay and Port of Newark. This waterway is commonly referred to as the South Way providing waterway access to Upper New York Bay and Newark Bay and it is used by container vessels servicing the Howland Hook Container terminal just north of the site and refineries to the south.

Though a vast amount of ship population data is available for the site, all of which could be used to support an AASHTO-based ship collision study, the owner chose to approach ship impact risk mitigation following a prescriptive approach. This is in part achieved by prescribing a span that places the towers well back from the navigable channel, and also includes a fender wall on the New Jersey side that barricades the narrow waterway slip where the NJ tower is located. On the New York side of the channel the tower is set back far from the channel, but could potentially be impacted in an extraordinary occurrence. For this reason the owner prescribed three specific risk vessels and corresponding displacement for each. These include a 100,000 DWT tanker ship, a similar 50,000 DWT ship and a Jumbo Tank

Barge. Corresponding vessel speeds were defined as 10 knots, 12, knots and 8 knots respectively.

The design team undertook a detailed study assessing the potential for vessel collision, and a determination of the associated collision loads. These studies were undertaken by Parsons in-house expertise in collaboration with Bittner-Shen Consulting Engineers. Overall the study focused on the bathymetry of the New York shoreline since it was apparent that the channel bank would likely prevent a ship from reaching the new bridge piers, thus eliminating the risk of pier damage. A grounding simulation analysis was undertaken using the GRACAT software, published by the Technical University of Denmark.

The study concluded that the loaded tanker ships would not reach the pier as a result of grounding. However, it was found that an empty 50,000 DWT tanker ship might possibly impact the westerly face of the pier footing, but only in a glancing blow scenario. This conclusion conservatively discounts the effects of ship redirection as it initiates grounding on the sloping river shoreline.

Following the prescriptive ship risk vessel parameters, and the study undertaken by the design team, the piers are designed for the extreme event ship impact load upwards of 10,000 kips resulting from a glancing blow impact from an empty 50,000 DWT approaching the New York tower pier at a speed of 12 knots. The event can be sustained with minimal damage overall, but some repairable damage at the footing level. All in all, the new bridge design is well protected from ship impact risk.

Conclusion

New York City is a city of bridges. The New Goethals Bridge will be the first major bridge constructed in the city since the Verrazano Narrows Bridge in 1964, and with this new era of bridge building, the Port Authority of New York and New Jersey has again advanced the state of the industry by implementing unique loading criteria, stringent service life requirements, prescribed sustainability and resiliency requirements and a dedicated maintenance provider. The New Goethals Bridge will long stand as a symbol of the Port Authority's commitment to the economic vitality of the New York metropolitan region.