ASSOCIATION OF CONSULTING
ENGINEERING COMPANIES
BRITISH COLUMBIA

McElhanney

COMMUNITY CONNECTION

The Atal Setu Bridge creates critical link between Northern Indian states

Prepared for the 2017 Canadian Consulting Engineering Awards

Submitted by McElhanney Consulting Services Ltd.

Category: B. Transportation

CONFIRMATION RECEIPT & ENTRY CONSENT FORM

THE ATAL SETU (BASOHLI BRIDGE)
PROJECT INFORMATION

INNOVATION

The Atal Setu is the first design-build cable-stayed bridge in India.

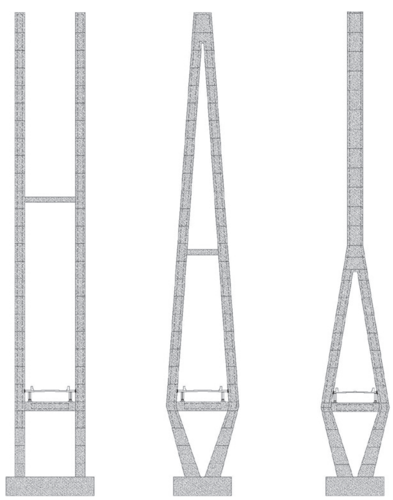
The Atal Setu Bridge is the first cable-stayed bridge in India procured under a design-build contract to connect the states of Punjab and Jammu & Kashmir across the River Ravi in Northern India. This new connection has reduced travel times by over four hours, and created a critical link for emergency response access to the Kashmir Valley. In August, 2010, Border Roads Organization of the Ministry of Defence selected the contractor team of IRCON/SP Singla Constructions Pvt. Ltd. to construct the 592m-long bridge through a highly competitive design-build bidding process. The contractor engaged McElhanney Consulting Services Ltd. as the prime consultant for the conceptual and detailed design, construction engineering, and site support aspects of the project.

The foremost challenge was to develop a design concept that suited the unique site conditions and reduced construction cost and duration while respecting the bid documents' constraints. The bridge site is located in a high seismic region near the Eurasian and Indian tectonic plates, where several severe earthquakes have occurred. Considering the narrow bridge deck of 13.2m and base wind speeds of 140km/h, aerodynamic stability was also a significant concern. The reference concept in the design-build contract fixed the span arrangement, the deck width, and the top and bottom tower elevations. The reference concept was a three-span symmetrical cable-stayed bridge with a 350m main span, two 121m side spans, two planes of cables attached to diamond-shaped towers, and a superstructure of a cast-in-place, two-celled triangular concrete box girder system. Described below are the key innovative refinements to the Atal Setu's reference concept that enhanced the efficiency of the structural system and minimized the cost.

Modified diamond-shaped towers

Similar bridges either employ diamond-shaped or H-shaped towers. Diamond-shaped towers are favourable from a seismic perspective due to compact bases, but are more challenging to build. H-shaped towers are easier to construct but are not favourable with respect to seismic response or aerodynamic stability. Therefore, McElhanney's team developed modified diamond-shaped towers that worked well in a high seismic zone but also were easier to construct given local constraints. The diamond portion of the tower was kept as small as possible based on geometry and traffic clearance constraints; while the upper portion was designed as a 53m vertical cantilever that incorporated all the cable anchorages. Construction of the vertical cantilever was simpler and faster than the inclined legs and it permitted superstructure cantilevering concurrently with tower construction, once tower construction passed the lower cable anchorages. Forty-eight cables of each cable plane were connected to the central vertical leg, which provided aerodynamic stability against twisting effects. With the tower and cable configuration aiding in the wind stability, the main span superstructure could be a lightweight edge girder system, easier to fabricate and erect than stiffer box shapes.

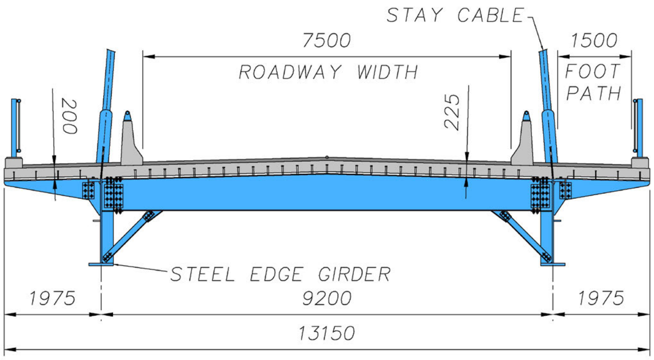
The Bridge Tower Report Card



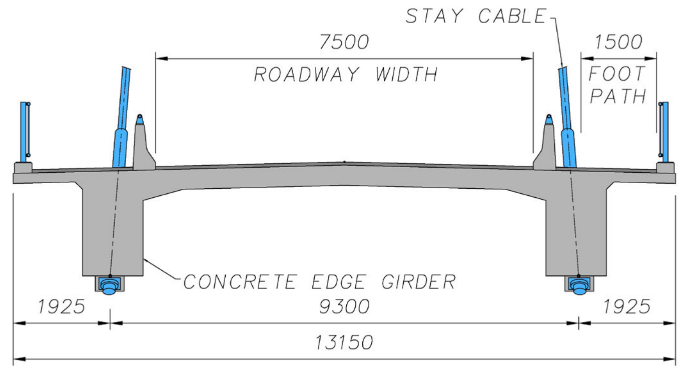
	H-Shape	Diamond	Modified Diamond
Seismic Response	C-	A+	A+
Aerodynamic Stability	C-	A-	A
Construction Ease	A	C-	B-

Unique hybrid superstructure

Most modern cable-stayed bridges have superstructures that are made entirely of either composite steel or concrete. Taking advantage of the shallow natural terrain on either side of the river, the team was able to use a unique combination of composite steel in the main span and cast-in-place concrete for the side spans. This hybrid system not only provided significant construction advantages discussed below but also assisted in eliminating uplift at the abutments. The most vulnerable component on a cable-stayed bridge is the uplift anchorage. In this case, McElhanney's team needed to address the permanent load imbalance from the side spans, which were shorter than usual in relation to the main span. To do so, the lightweight composite steel girder system with a 225mm deck in the longer main span was counterbalanced by the heavier concrete edge girder system supporting a 400mm deck in the shorter side span. The hybrid system allowed multiple work fronts, meaning that the contractor could undertake parallel activities. While the main span steel components were being fabricated in the shop, the side spans were cast-in-place on a temporary support structure at the same time the towers were being built.



Bridge main span - composite steel



Bridge side span - cast-in-place concrete

After the side spans and the towers were cast, the contractor could erect the main span using progressive cantilevering, which offered greater stability and safety compared to balanced cantilevering.

Novel intermediate pier props

An innovative feature of the design was the introduction of three sets of intermediate pier props in the side spans that help stiffen the tower and superstructure and reduce demands from wind and live load by over 50%. The intermediate pier props were installed after the bridge was completed and support a portion of live loads but do not carry the weight of the bridge. These relatively inexpensive tension/compression piers only needed to be 10m tall because the side spans were already low to the ground, owing to the shallow natural terrain. Though the piers may seem relatively insignificant, they led to major material savings in the superstructure and tower. The savings became even more appreciable for this bridge as it is designed to Indian Road Congress (IRC) code, where the live load requirement is one of the heaviest in the world and includes provisions for military tanks crossing the bridge. Similar bridges with low-to-ground side spans generally provide standard bents to support the superstructure, including resisting lateral load effects, and require a significant structure with foundations.

Intermediate pier props

KEY CHALLENGES

- Strong winds (140 km/h)
- Hight seismic activity
- Steep banks and high water fluctuations (6m), precluding erection from below.

SOLUTIONS

1. Compact tower base for reduced seismic response.
2. 53m-long vertical tower element allowed for faster construction.
3. Cables form a closed triangle with deck to resist twisting from wind.
4. Unique combination of composite steel edge girder superstructure in main span with 5 concrete side span constructed on temporary support structure taking advantage of natural terrain.
6. Overhead material deliver to gantry along previously constructed sidespans.
7. Custom erection gantry for rapid progressive cantilevering of steel main span from above.

COMPLEXITY

The team cut construction time by more than half compared to similar scale cable-stayed bridges in India.

The site has steep rocky banks with large river water level fluctuations of 6m that made transport of material and erection from the water very difficult. A customized gantry was developed to lift the superstructure steel segments from overhead and hoist them into position from the previously constructed superstructure in a progressive cantilever manner. The material was transported along the side spans, which were completed on falsework prior to the main span cantilevering operations.

Aside from technical challenges, the team faced several important project management challenges. The contractor required an extremely aggressive design schedule of only six months compared to the 9 to 12 months usually allocated for the design of similar cable-stayed bridges procured under a design-build scheme. The schedule for this bridge was compressed because, after award, as is common in India, the contractor solicited value engineering proposals from multiple consultants to reduce project costs. This consultant selection phase stretched longer than anticipated, however, consuming five months of the active design-build contract period, before McElhanney was appointed as the prime consultant. McElhanney successfully delivered the design plans within six months, recovering the initial time lost and allowing construction to commence as planned.

Other factors that increased complexity relative to similarly sized projects in North America include a foreign contractor with no previous experience in cable-stayed construction that needed exceptional support beyond North American norms in construction scheduling, development of construction methodologies and vetting of sub-contractors; a 12-hour time difference between India and Canada; and significant cultural differences. To mitigate the potential coordination problems, upon award of the project, McElhanney established a project office in Gurgaon, India, staffed with personnel from Canada, several of whom spent significant lengths of time on-site supporting the construction. This office facilitated better communication among team members, aided in understanding and interpreting the IRC code, and added further support for the client's proof-checking process performed by IIT Delhi.

McElhanney's Chad Amiel on-site for the construction of the side spans and towers.

The construction of the side spans and towers.

SOCIAL AND/OR ECONOMIC BENEFITS

Connecting isolated communities and three states enhanced nation-building.

Every evening when Senior Site Engineer, Morgan Trowland, walked back from the site, shopkeepers would ask him when the bridge would be finished, some of whom had been waiting 50 years for this structure to enhance tourism and travel through the area. During construction, local work force was used for labour-intensive activities in casting the side spans and towers, stimulating the local economy.

Since completion, the bridge has reduced travel time from Basohli in Jammu & Kashmir to Dunera in Punjab by over four hours. This major time-savings has meant a boon for the previously isolated communities living across the river in the Himalayan town of Basohli, drastically improving locals' quality of life.

Reports already indicate an economic boost from increased tourism activity to the scenic region and the commercial mining of gypsum and limestone. Small businesses and restaurants are sprouting up on either side of the bridge to cater to the needs of tourists and industry commuters. The connection has empowered the local communities by renewing inter-state business, art, and cultural exchange – including revival of nuptial ties, as families have started considering arranged marriage proposals from across the river. The connection is also encouraging local youth to consider educational opportunities in more prestigious colleges across the river. Security in the region has significantly improved now that troops have quick access to the insurgency-prone areas in the Kashmir Valley.

The much-anticipated opening of the bridge drew a huge crowd for the inauguration by the Defence Minister of India. This landmark bridge is being proudly described by the local community as an "engineering marvel."

ENVIRONMENTAL BENEFITS

The team developed a sustainable design harmonious with natural terrain without impact to river ecology.

The design team selected recyclable construction materials and configured them based on structural efficiency and constructability. Locally sourced material was used for all the cast-in-place concrete works in the towers and side spans. As mentioned above, the use of the novel intermediate pier props and the modified diamond-shaped towers significantly increased structural efficiency, thereby reducing the overall material consumption and provided structural longevity.

The bridge was designed to have minimal interaction with the river, without any permanent or temporary foundations in the riverbed. All the superstructure elements were delivered and erected from overhead, which minimized environmental impact to the river ecology.

Careful attention was paid to the durability of the permanent components to ensure longevity of the bridge. Concrete components were detailed to limit cracks and distribute them over wider areas. The team designed steel components to provide easy access for inspections and maintenance. All bridge components that do not have an equivalently long life, such as cables, bearings, and expansion joints were designed to be replaced. Each cable has the provision for adding supplemental strands to accommodate a marginal increase in future traffic loading. The team also developed a maintenance manual documenting rigorous inspections and upkeep procedures and provided this to the owner.

MEETING CLIENT'S NEEDS

Extensive kowledge transfer to local contractor without previous cable-stayed experience.

Minimize material quantities

The bridge was completed within a budget of $32M USD ($5,000/m^2) which is extremely cost-effective for a bridge of this nature. Bridge costs in India are directly proportional to material quantities as labor cost is generally much lower compared to North America. The contractor requested a design that minimized material quantities to minimize cost. This required an innovative design to efficiently overcome difficult access conditions, extreme seismic activity, and high winds described in detail in ***SECTION 1***. A unique material combination of a composite steel main span balanced by cast-in-place concrete side spans, including intermediate pier props in side spans that significantly reduced demands and thereby material consumption.

Technology transfer to contractor

As this was only the fourth cable-stayed bridge built in India, the successful contractor did not have previous experience in cable-stayed technology. This required McElhanney to provide exceptional support to the contractor's crew over and above North American norms in developing construction methodologies, scheduling activities, geometry control, and vetting of sub-contractors to bridge technology gaps on the design-build team. McElhanney set up a local office in New Delhi and relocated the Canadian design team to produce the design plans in close collaboration with the contractor. A full-time engineer was stationed at the site to monitor construction and coordinate with the home office and the construction crew. The home office provided prompt trouble-shooting support to the construction site. During the rapid progressive cantilevering of the main span, McElhanney's team immediately processed survey data and recommended adjustments to the target cable forces for geometry control to keep pace with the schedule.

Complete construction in four years

The Atal Setu was procured under a design-build scheme to complete the project rapidly, however the project was off to a slow start as five months were consumed in consultant selection. This required the prime consultant to search for schedule savings during both the design and construction phases. McElhanney's team recovered the lost time from the consultant selection phase through a much shorter design period of only six months. All project deliverables were completed on time and on budget, accelerated methodologies were developed to speed up construction including the overhead delivery and erection scheme for the main span and for the critical closure operations for the bridge cantilevers at mid-span. The bridge opened to traffic in December 2015, after just 4 years of construction, cutting the construction time by more than half when compared to similar cable-stayed bridges in the country.

CONCEPT SKETCH

KEY CHALLENGES

- Strong winds (140 km/h)
- Hight seismic activity
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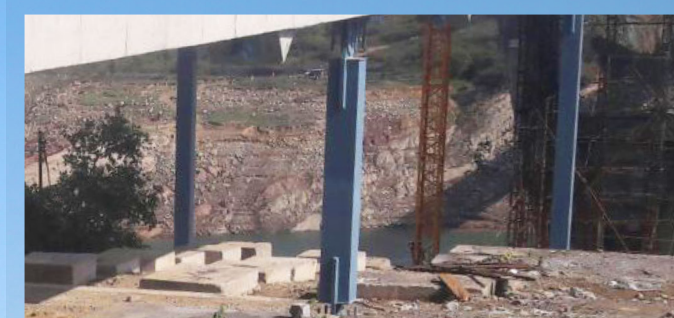

(A) MAIN SPAN CLOSURE: THE GOLDEN HOUR

- Thermal movements caused the closure gap to vary by 55mm throughout the closure day.
- The team discovered that 4:00p.m. was “the golden hour,” when expansion slowed to zero and began to reverse.
- The contractor cut the closure segments to fit the gap measured in the golden hour.
- Bolt holes of the final splice had to be drilled in the golden hour, and the team ensured the holes were aligned and bolts were inserted at 4:00p.m. on closure day.

(B) NOVEL INTERMEDIATE PIERS

- Simple low cost tension/compression props stiffend up the side span superstructure and towers, reducing demands from live load and wind by over 50%. This innovation meant significant material savings for the project.