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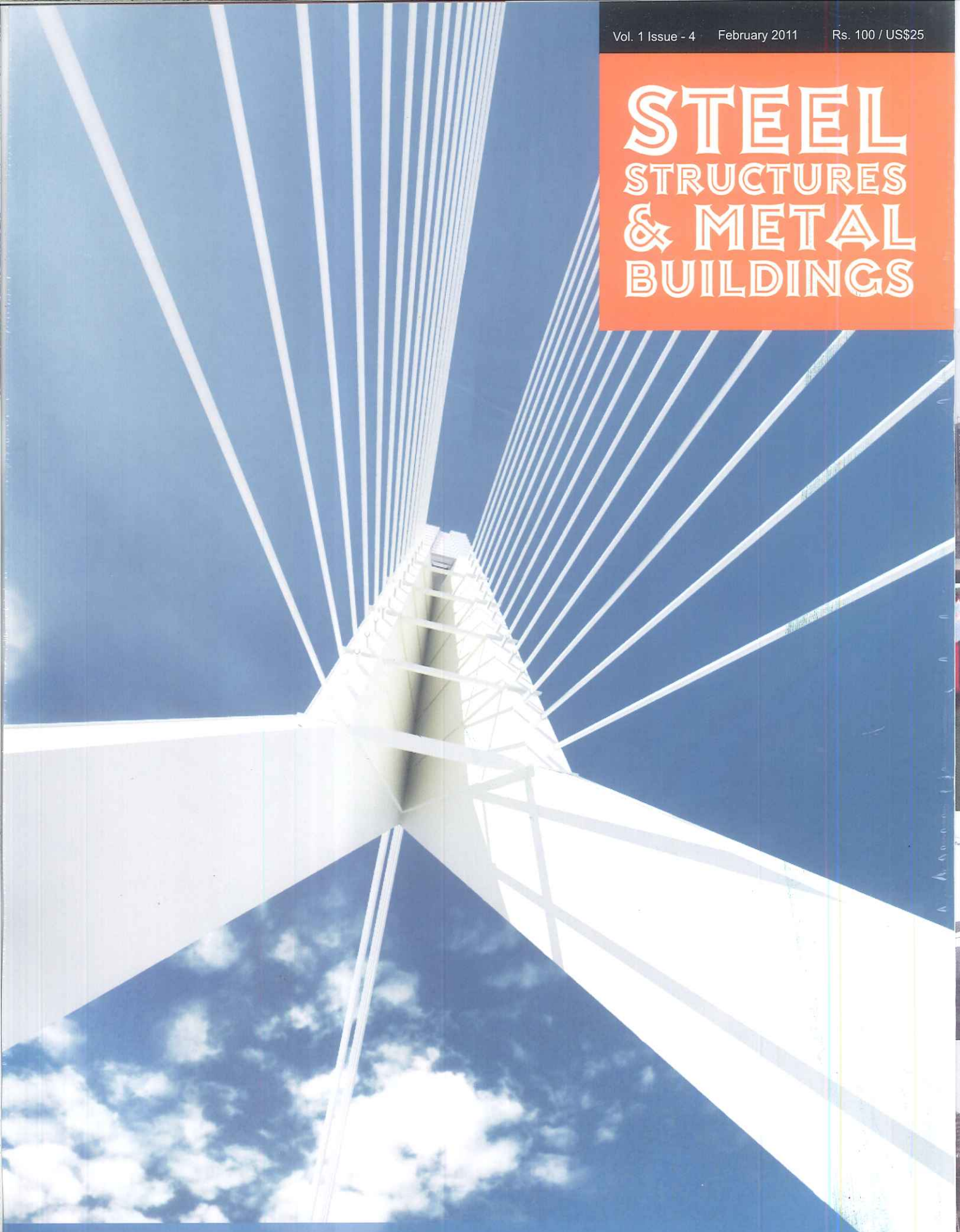
STEEL STRUCTURES & METAL BUILDINGS

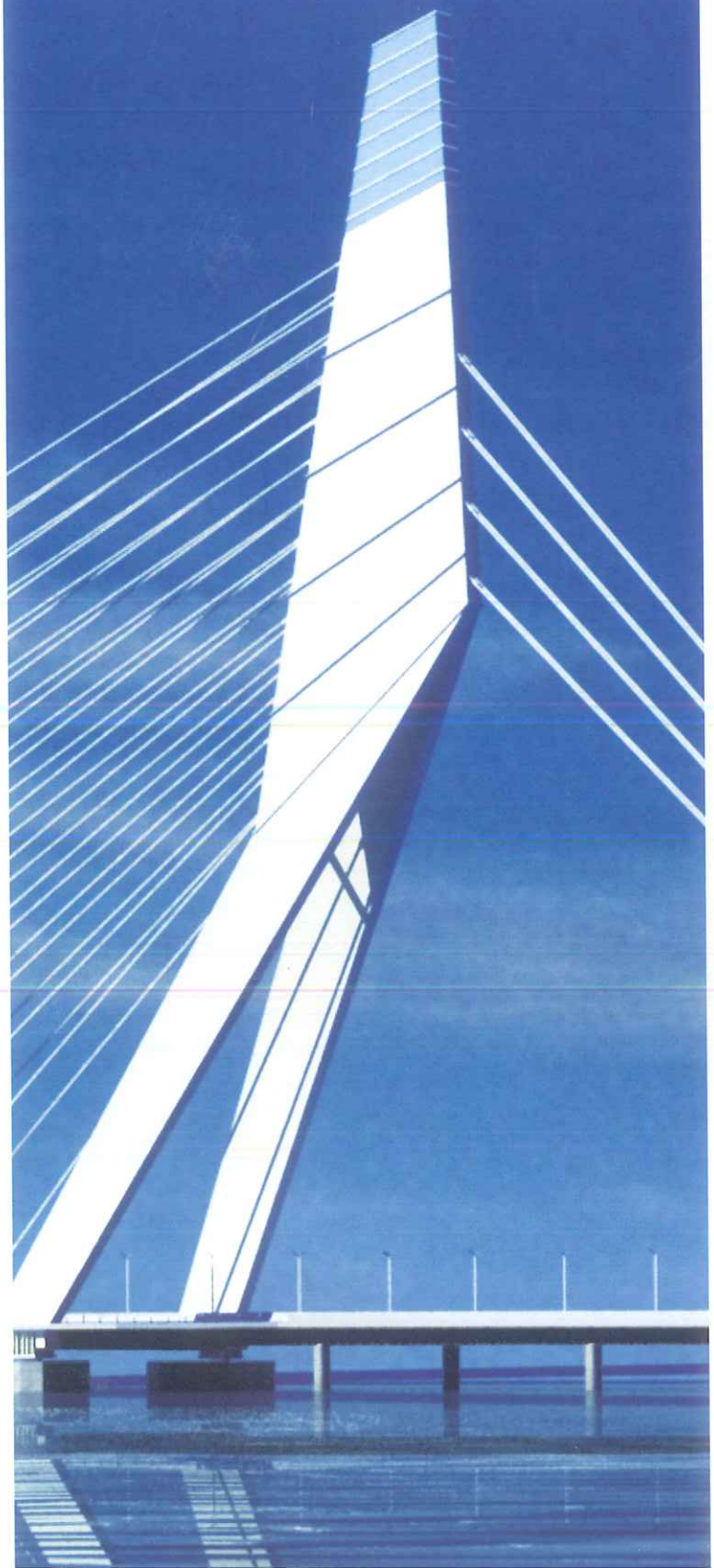


STEEL: bridging the gap

Cover Story

YAMUNA BRIDGE

AT WAZIRABAD, DELHI



conceptual and structural design

Although steel is used in bridge construction since many years across the globe, but going by the latest progress in the technology materials, steel has had a big impact on the development of planning the bridges in India. Research in the quality of steel used in construction of bridges have made the production and installation of long span steel bridges safe and straightforward.

Steel bridges can now be tailor-made or adjusted to the conditions in the field perfectly. From an engineering viewpoint, the purpose of a bridge is not just to span some physical obstacle, but to distribute forces evenly through a few key points in a structure. Here, we showcase the structural design analysis of India's first 'Signature Bridge', currently being constructed at Wazirabad - a customized bridge, which is explicitly called for by the Delhi Tourism and Transport Development Corporation to create a new symbol of Delhi.

Fact File

Client
Delhi Tourism and Transportation Development Corporation

Designers:
Schlaich Bergermann und Partner, Germany in JV with Construma Consultancy Pvt. Ltd (CCPL), Mumbai

Architectural Advisor
Ratan J. Batliboi – Architects Pvt Ltd, Mumbai

Wind Tunnel Studies
Wacker Engineers, Germany

Seismic Studies
IIT Roorkee

Checking Engineer
Systra and M.Virlogeux, France in association with Tandon Consultants, New Delhi

Construction
Gammon-C.Cidade-Tensacciai JV

India's first 'Signature Bridge', being constructed across the Yamuna River at Wazirabad, promises to be a great attraction of New Delhi. An ambitious project of the Delhi Tourism & Transport Development Corporation, the cable-stayed bridge will link National Highway number one near existing T-point at Wazirabad on Western bank and Marginal Bund Road at Khajuri Khas on Eastern bank of Yamuna River, thus, connecting North Delhi with East Delhi. Considering the tremendous rise in population in the Trans Yamuna area, there is a pressing demand for an East-West corridor on the river.

Once operational, this 'Signature Bridge' will dramatically improve access between North and West Delhi for the commuters, who have to pass through the narrow lane on the present bridge in Wazirabad, leading to heavy traffic jam in the peak hours. Also, to facilitate the movement of vehicular traffic, new express lanes will be constructed to connect Ring Road with the bridge.

One tower will be there to provide cable support in the outer periphery of the carriageway. Plans are also afoot to construct a pedestrian sub-way at an approximate cost of Rs 29 lakhs. Equipped with two four-lanes, this engineering masterpiece will have 2.0 meter wide side verges, space for anchoring cables, maintenance walkway and crash barrier on either side of the deck. The deck will be composite (steel and concrete) while the pylon will be in steel.

Conceptual Design

The Yamuna Bridge at Wazirabad is an unsymmetric cable-stayed bridge with a main span of 251 meters and total length of 675 meters. The bridge's composite deck carries 8 lanes (4 in each direction). It is about 35 m wide and is supported by lateral cables spaced at 13.5 meters intervals. The height of the steel tower is approximately 150 meters.

The Bridge is one of the many infrastructure projects that are presently being built in New Delhi. The area around the bridge will later be developed into a park and the Yamuna River will be widened to lake-like dimensions. Therefore, the client, had asked for a rather long-span but light-weight bridge and a signature design which

VIRTUOSO QUOTE

Mike Schlaich

Managing Director, Schlaich Bergermann und Partner, Germany

"Structural and civil engineers are responsible for all built infrastructure such as roads, tunnels and bridges. This is quite a responsibility, as these structures can add value to our environment or do harm. Bridges, perhaps the prototypical buildings of the engineer are most apt to show the potential we have to contribute to the culture of building."

could become one of the area's attractions and a landmark for New Delhi. Based on this context, during various design sessions, numerous alternatives for the future bridge where drafted and evaluated. The outcome is a cable-stayed bridge which has some novel features that make it easily identifiable and that provide it with a signature appearance.

At the same time, the design evolves from well proven structural solutions such as a slender composite deck. Such a deck was used for the first time for the Second Hooghly Bridge in Kolkata, the first cable-stayed bridge in India, and has become common practice world wide. Once approved by the Delhi Government and the Delhi Urban Arts Commission the design of the Yamuna Bridge was further developed. The most striking feature of the bridge is the inclined pylon which in addition to its structural function leaves ample room for symbolic interpretation. The top of the pylon is formed by a steel-glass structure which houses an inspection platform that can also be used as a viewing platform.

It is envisaged that this glass pylon head can be illuminated at night, thus, converting the pylon into a beacon or torch that can be seen from a long distance. Small elevators will be integrated into the interior of the tower legs, thereby, permitting easy access to its top. The layout of the upper part of the pylon allows for large scale artistic painting, which is not possible with pylons of conventional cable-stayed bridges. Applying typical Indian ornamental graphics to the pylon top will further enhance its uniqueness.

Due to its inclination, the pylon weight can compensate a significant part of the dead load of the main span. This cable-supported part of the deck spans 251 meters crossing the area of the future lake without supports to the ground. Towards the approaches the same deck section continues with piers supporting it at 36 meters intervals. The pylon is located towards the eastern shore, forming a gateway that connects the Wazirabad area to New Delhi. The result of the conceptual design process for the Yamuna Bridge is a structure which tries to combine robustness and structural sanity with the expectations that come with a Signature Bridge.

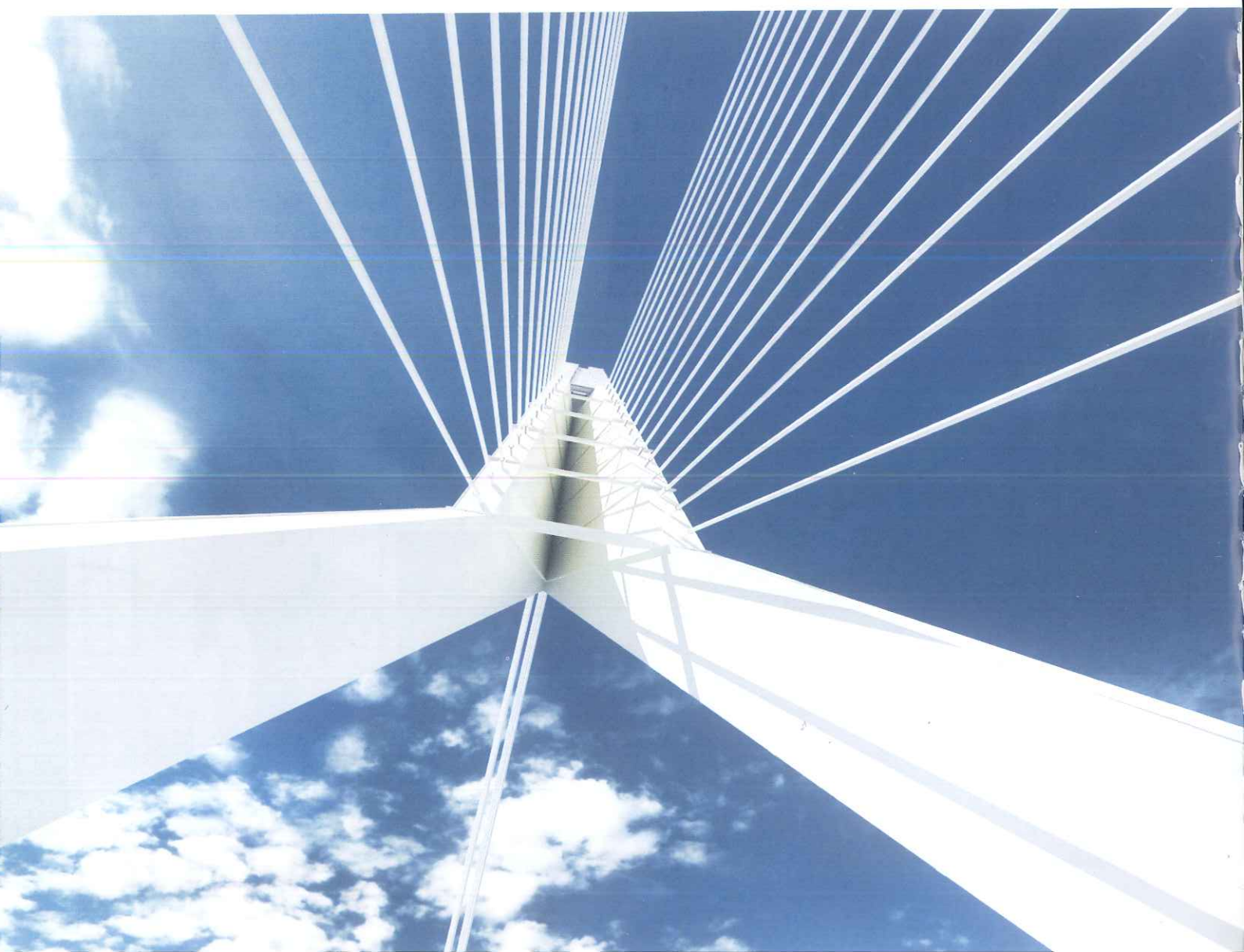
Structural Design

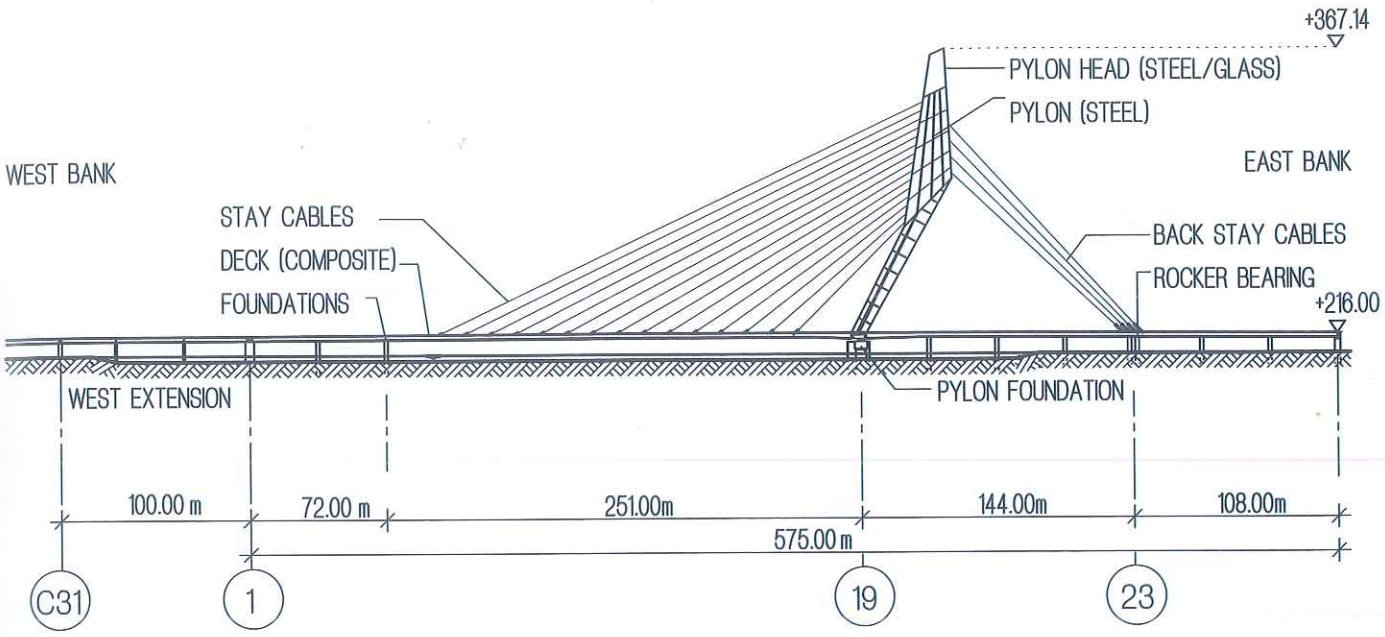
The bridge consists of a steel tower and a composite deck that are supported on a series of open and well foundations.

Deck

Two carriageways, typically 14.00 meter wide and separated by a concrete crash barrier as well as two lateral emergency pathways, form the deck of the bridge that totals 35.2 meters in width. Each of the carriageways accommodates four traffic lanes. The deck is formed of outer I-shaped longitudinal main girders and I-shaped cross girders at 4.5 meter intervals. A third central main girder is placed to distribute heavy truck loads onto several cross girders. All structural steel is grade S355 (or the Indian equivalent). Shop welding and site splices with high strength friction grip bolts will be used. The pre-cast deck slabs of concrete grade M50 span 4.5 meters. Their standard thickness of 25 cm increases to 70 cm at the main tower and in the area of the backstay anchorage.

The composite deck not only permits quick and simple erection, but also offers the economical advantage of having concrete balancing the horizontal cable thrust, a cost-free prestress. The deck is transversally supported on both ends of the bridge and at the pylon. The only longitudinal deck support is at the pylon. The longitudinal movement of the deck at its western end is 250 mm approximately.





Cables

The deck is supported by two cable planes. The cables are directly anchored to the webs of the outer main girders at 13.5 meter distances with their dead end, and are stressed within the stressing chambers at the top of the pylon. The cables will be made of bundles of parallel 0.6" strands of grade 1770. Depending on the location the number of strands per cable varies from 55 to 123 nos. at the main span and is 127 nos. for each of the backstays. Corrosion protection will be to international practice, i.e. with hot dip galvanized wires and individually coated strands that are covered by an outer PE-pipe. In the backstay area the lower part of the cables will be covered with steel tubes for fire protection.

Pylon

The pylon consists of two legs made of steel boxes which merge into one upper pylon zone, where the cables supporting the main span and the backstays are anchored and interconnected. Also the upper tower is designed as a hollow box section, made of a load bearing skin stiffened by internal stiffeners and bracings. The pylon is monolithically connected to the deck. It introduces horizontal forces in the longitudinal direction into the concrete of the deck. The horizontal forces in the transverse direction are taken by a strong steel cross girder that connects the two legs at the level of the cross girders. Below the deck the pylon legs are supported on large pot bearings in order not to introduce bending into the substructure. Each bearing has to transmit vertical forces of 170.000 kN.

The major part of the steel for the pylon will be of grade S355. In very highly stressed zones, such as the area where the pylon is bent, grade S460 steel will be used. Above the top-most cable anchorage, the pylon rises further to about 20 meters forming the pylon head, a glass-covered steel structure that houses the illumination system and the platform mentioned earlier. During the monsoon season, strong floods are expected (HFL 210 meters approx., deck level at 216 meters).

Foundations

The maximum scour level for check flood is about 178 meters and for normal flood, considered for seismic case, about 182 meters. The rock levels vary in between 193 meters and 173 meters.

As stated earlier, this is a unique bridge and the scheme of the bridge also demands solving difficult problems in the design of the foundations in varied founding soil strata. Six foundations are made as open foundations with spread footing and 16 foundations are well foundations. Out of 16 well foundations, 8 are

VIRTUOSO QUOTE

Harshavardhan Subbarao

Chairman and Managing Director, Construma Consultancy Pvt Ltd

"Most cities in the world are known by their Bridges. Connecting East and West Delhi with an Iconic Bridge in the historical Capital of India, symbolizes the rising aspirations of modern India. When the Master Plan is fully implemented, this extraordinarily engineered Signature Bridge will be showcased in the midst of a large water body and specifically landscaped and wooded surroundings. Together the Bridge and its environs will serve as a unique Tourist destination."

founded on alluvial soil and the balance on undulated rock, not only in the longitudinal direction but also in the transverse direction. Some of the foundations are designed with very high horizontal force and some with very high uplift force. Liquefaction of soil during a seismic event and high scour in Yamuna River are taken into account in the design. It was planned that the construction of the well foundations would be done using jack down method due to which there are saving in quantities of concrete and steel. This method also allows effective control during well sinking to avoid tilt and shift including when wells get stuck in stiff clay. The schemes of the foundation design were made on the basis of vast experience on the outstanding foundation design of many major bridges in India like Second Hoogly Bridge and Varanasi Bridge.

Erection

Since presently no lake exists yet, and since the deck is not high above ground, the usual free-cantilevering erection of the deck of cable-stayed bridges is not necessary. Rather, the deck can be built on temporary supports. Those, however, have to be able to resist high waters should deck erection continue during the rainy season. The pylon will be assembled of prefabricated and machined elements which will be lifted by heavy cranes and then be welded or bolted together at there final location.

Analysis

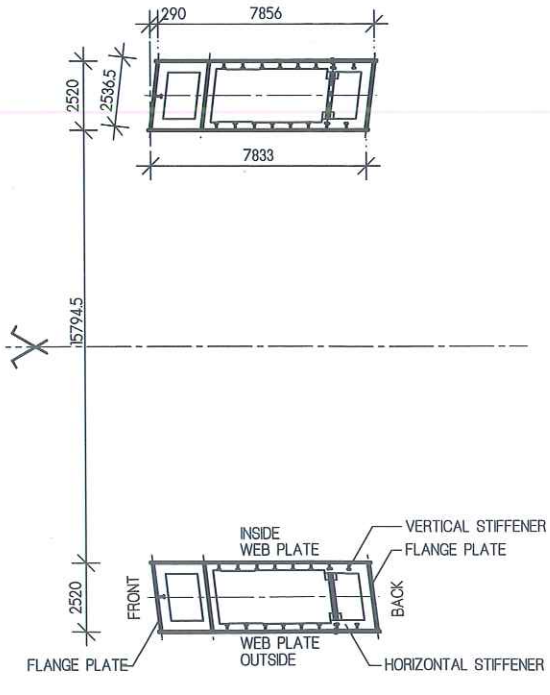
The structure has been designed according to Indian regulations, i.e. using allowable stress design and loads according to IRC:6-2003. For areas where Indian codes are not available or not applicable, Euro codes were used. For the design of the cables Setra guidelines on Cable Stays were consulted. For global analysis a 3D Finite-Element-Model of the bridge was used. The deck was modelled using shell elements for the concrete slab rigidly connected to beam elements which represent the steelwork below. The deck is designed to withstand the failure of any one cable and it is this load case that often governed the design. The pylon was also modelled with 3D shell elements.

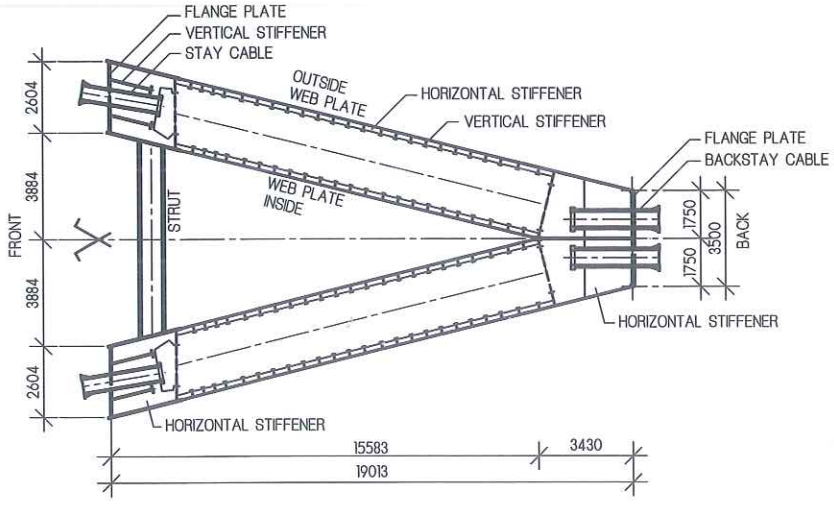
Second order effects were considered by geometrically non-linear algorithms applied to the pre-deformed system. It should be noted, however, that even today it is not possible yet to realistically model all details of such a complex structure by computer. The number of elements would become so large that not only would computing time become prohibitive, but, also the output would be so voluminous that it would become hard to interpret the results. So computer analysis must always be accompanied by conventional approximations for comparisons and checks.

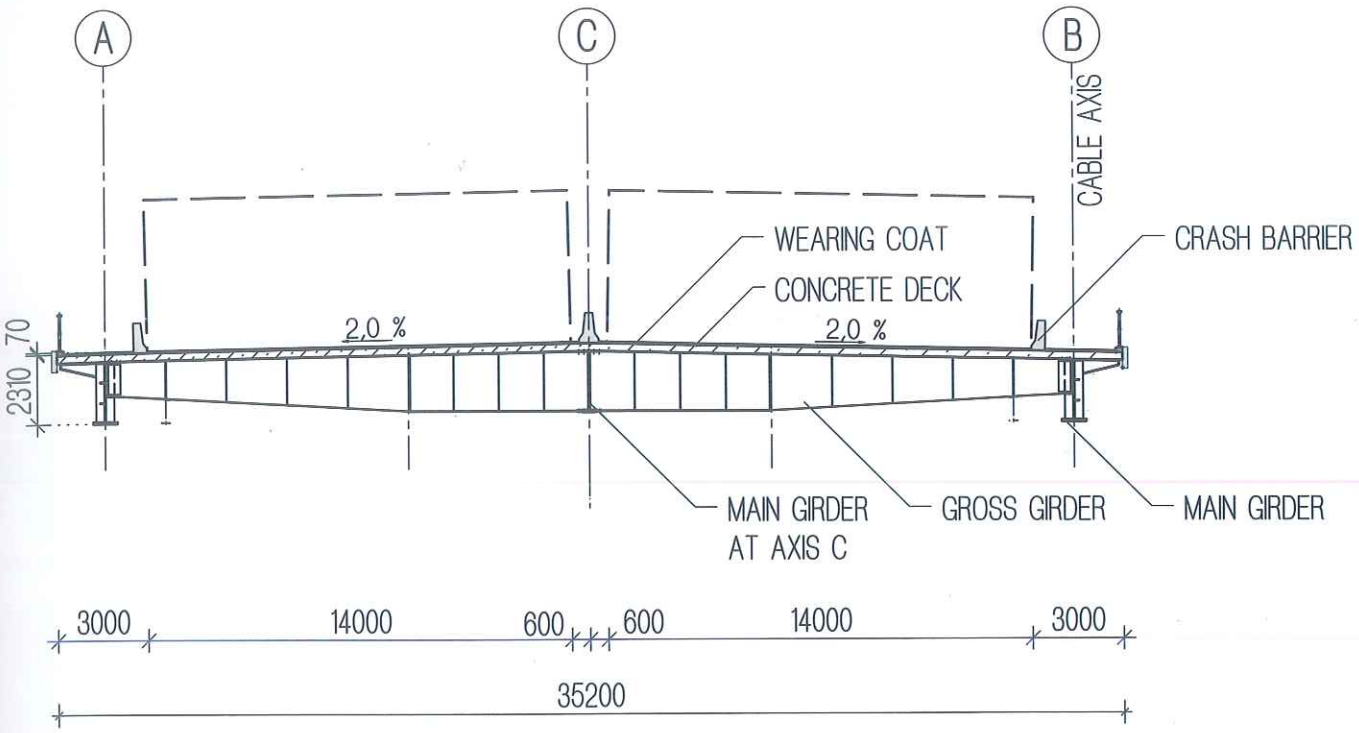
Extensive seismic analysis was done using three methods:

(i) Equivalent static method
(ii) Response spectrum method
(iii) Linear time history analysis method

The results of the studies show that seismic forces from the equivalent static method with a uniform lateral load of 10 per cent of gravity are on the safe







side. In the wind tunnel section model tests proved that flutter is no issue. Of importance was the modelling of the pylon in order to get realistic assumptions for the wind loads to be applied. The average transverse wind load (based on a design wind speed with a 100 year return period) that was applied to the pylon, is in the order of 1.7 kN/m2. Local peak loads for the glass design at the pylon head are up to 4.2 kN/m2.

To design a bridge, especially a cable-supported one, is a challenge every structural engineer is eager to face. The design of the Yamuna Bridge at Wazirabad certainly was such a challenge, a fulfilling one.

Salient Features

- Graphics on bridge structure is featured for the "first-time" in the world. The pattern chosen reflects Indian culture at the same time symbolizes a modern and progressive India.
- The bridge has been designed as a tourist destination by developing area around the bridge into public plazas and parks and made it accessible to the masses.
- Sheer scale and dynamics of the bridge, clubbed with cutting edge technology used in designing it, will make it a contemporary landmark for the city of Delhi and also in the world.
- Once completed, the bridge will help in changing the socio-cultural fabric of the area by attracting large number of tourists - local, national and international.
- On a mega scale, the project attempts to integrate and curb water pollution and encourages the Yamuna River cleanup, in turn, providing a water front worthy of tourist activities.

Data Sheet

- Total length – 675 meters (8 lanes)
- Main span – 251 meters
- Main tower height – 150 meters
- Deck surface - 21000 m^2
- Structural steel pylon - 5800 tonne
- Structural steel deck - 7400 tonne
- Open Foundations – 6 nos.
- Closed Foundations – 16 nos.

(Contributed by:
Project Teams of Schlaich Bergermann und Partner, Germany,
Costruma Consultancy Pvt. Ltd (CCPL), Mumbai
& Ratan J. Batliboi – Architects Pvt Ltd, Mumbai)

VIRTUOSO QUOTE

Ar Ratan J. Batliboi
Founder, Ratan J. Batliboi – Architects Pvt Ltd

"Infrastructure projects in India are generally not 'well thought-off' and mostly address the immediate problem. With this bridge, we are trying to change that by preparing an overall master plan for the bridge and surrounding area in order to develop it into an attractive tourist destination. It will be an ideal example of how well designed infrastructure projects and public amenities touch millions of lives and change the socio-cultural fabric of the masses."