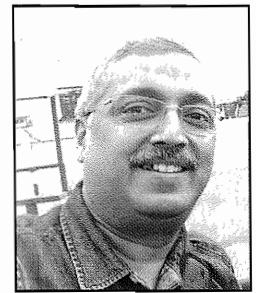


# LONG SPAN BRIDGES – STATE OF THE ART

by

**Shri Alok Bhowmick**



## **Abstract**

*This paper on state-of-the-art for long span bridges gives a broad overview of the evolution and present practices being followed around the world for bridges having individual span length exceeding 150m or so. The paper highlights the fast-paced progress made and dominant position taken in last two decades by China in the field of long span bridges and also shows India's poor record in this regard. Bridge types that fall under this category includes 'suspension bridges', 'cable stayed bridges', 'hybrid bridges', 'extradosed bridges', 'balance cantilever type girder bridges' and 'arch bridges'.*

**Keywords:** Long span; cable stayed bridge; suspension bridge; arch bridge; girder bridge; challenge; innovation

## **1. Historical Evolution of Long Span Bridges**

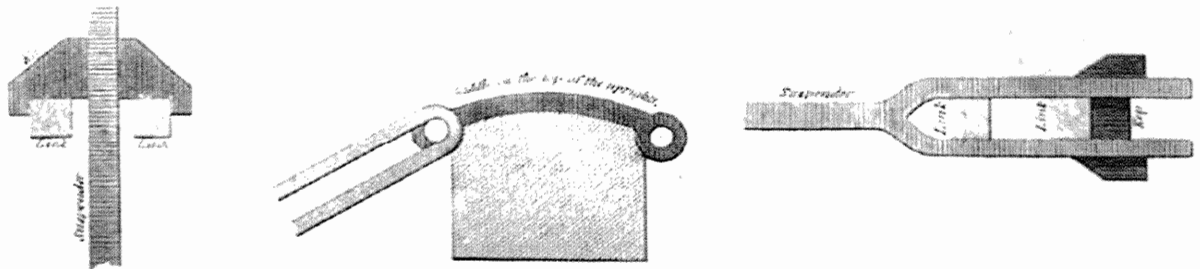
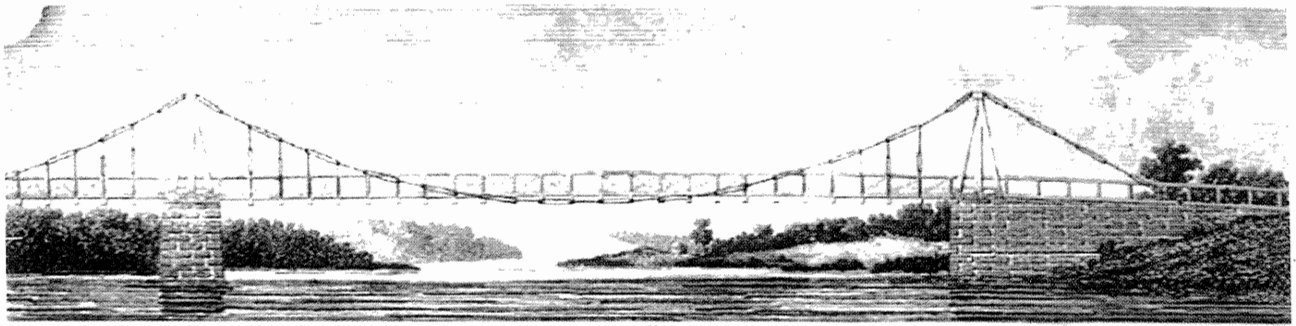
Civil Engineers have been building bridges for ages in order to cross rivers, valleys and streams. Over the years, with the technological advancement and scientific developments, the bridges are becoming longer, wider, complex and more and more complex. Long span bridges are generally classified into following categories :

- a. Suspension Bridges
- b. Cable Stayed Bridges
- c. Hybrid Bridges
- d. Extradosed Bridges
- e. Long Span Girder Bridges
- f. Arch Bridges

### **1.1 Suspension Bridges**

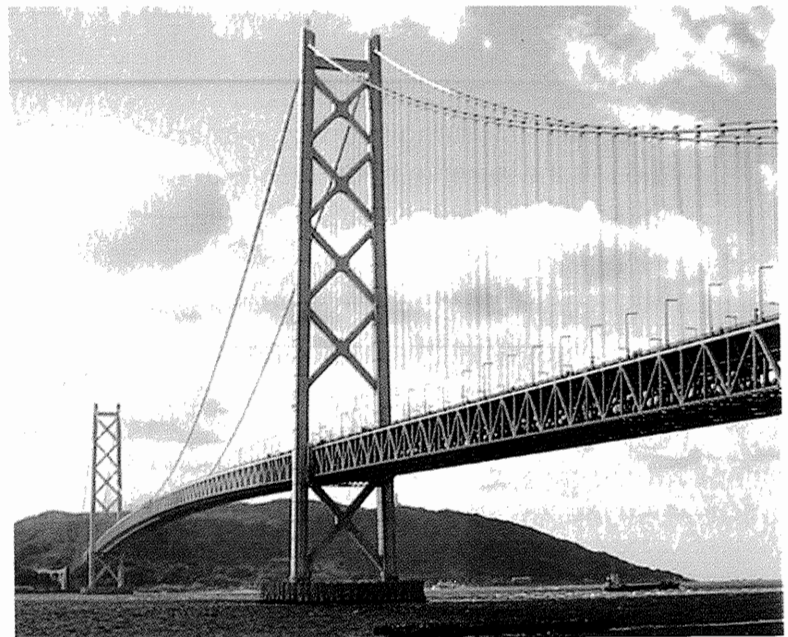
The first suspension bridge is the Jacob Creek Bridge, built in Pennsylvania in 1801 by the Irish judge and engineer James Finley (1756–1828)<sup>[Ref-1]</sup>. This is the first example of a suspension bridge using wrought iron chains and with a level deck (**Fig. 1**).

Since then, several suspension bridges were built in Great Britain during the nineteenth century. Quite soon however they showed to be quite pregnable in presence of strong winds. Between 1818 and 1889, ten suspension bridges suffered major damages or collapsed in wind storms, leading to evolution of new design concepts aimed at reducing the wind effects.



*Fig.1 : Jacob's Creek Bridge – First Suspension Bridge*

The construction of modern suspension bridges around the world has experienced a considerable development since 1883, when the first modern suspension bridge, Brooklyn Bridge in New York city, having a span length of 486m was built. It took about 48 years for the span length to grow from 486m to 1067m of George Washington Bridge in 1931 connecting New York and New Jersey in USA. The record of George Washington Bridge was broken within 6 years, when the famous Golden Gate Bridge of span length 1280m was constructed in 1937. Further development in next 44 years were slow in terms of increase in maximum span length and it reached to only 1410m for Humber Bridge, UK. However in next 18 years, the span length increased dramatically from 1410m to 1991m, when Akashi Kaikyo bridge was built in Japan (1998) (**Fig.2**). A bridge in Turkey (Çanakkale Bridge) is presently under construction having main span length of 2023m, which is likely to be completed in the year 2022. Once completed, this bridge will be holding the world record for longest span length



*Fig.2 : Akashi Kaikyo Bridge – Longest Main Span SB*

in the world.

The suspension bridges are typically a 3 span continuous module with one main span, two pylons having two side spans of approximately half of the length of main span. China took the lead in building multi-span suspension bridges having more than 2 pylons. 3 such bridges have been built in China around 2012 onwards (Maanshan Bridge (Main Span 1080m), Taizhou Bridge (Main Span 1080m), Yingwuzhou Bridge (Main Span 1080m)). **Table 1** gives the list of top 10 suspension bridges in the world.

**TABLE 1 : TOP 10 LONGEST SPAN SUSPENSION BRIDGES IN THE WORLD<sup>[Ref-2]</sup>**

Rank	Bridge Name	Main Span Length [m]	Deck Type	Country Located	Built Year
1	Akashi Kaikyo	1991.0	Two-Level Truss	Japan	1998
2	Xihoumen	1650.0	Streamlined Box Girder	China	2009
3	Great Belt	1624.0	Streamlined Box Girder	Denmark	1998
4	Osmangazi Bridge	1550.0	Streamlined Box Girder	Turkey	2016
5	Yi Sun-sen	1545.0	Streamlined Box Girder	Korea	2012
6	Runyang	1490.0	Streamlined Box Girder	China	2005
7	4th Nanjing	1418.0	Streamlined Box Girder	China	2012
8	Humber	1410.0	Streamlined Box Girder	UK	1981
9	Jiangyin	1385.0	Streamlined Box Girder	China	1999
10	Tsing Ma	1377..0	Two-Level Truss	China	1997

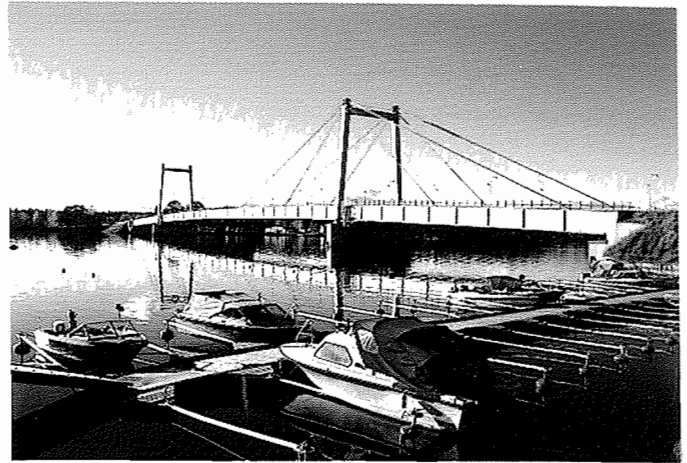
The design of long span suspension bridges are governed largely by wind effects, aerodynamic stability and resistance to extreme turbulent winds. From the above table, it is clear that for long spans, the trend is to go for streamlined deck. It may be noted that though the number of bridges with very long span is rather limited, but more and more bridges are erected worldwide with a main span in the range of 1000m and 1400m. A close look at the list of suspension bridges under construction indicates very interestingly the fact that 24 out of 28 bridges are located in China<sup>[Ref-2]</sup>.

India's record on Suspension Bridges is rather poor, in spite of the fact that Suspension Bridges originated in Indian sub-continent more than 3000 years ago. Most of the suspension bridges in India are for pedestrians and light vehicles, with span length generally not exceeding 300m. The author could not collect any statistics of the suspension bridges that exists in India.

## 1.2 Cable Stayed Bridges – 3 Span Module

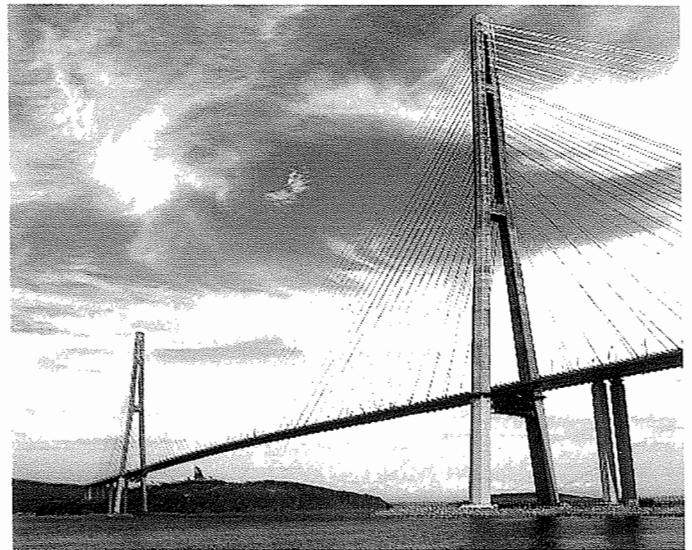
Stromsund bridge, Sweden, completed in 1955 is the first modern cable stayed bridge with a main span of 183m (**Fig.3**). It took about 20 years for the main span length to

increase to 404m in Saint-Nazaire bridge, France, in 1974. Within next 25 years, the main span length increased from 404m to 890m in Tatara bridge, Japan, which was completed in 1999. The span length of over 1 km was realised in Sutong Bridge, China, in the year 2008, where the main span length was 1088m. This was quickly followed by completion of Stonecutter bridge, Hongkong (2009) with main span length of 1018m and Russky bridge, Russia (2012) of main span length 1104m. **Table 2** gives the top 10 longest span cable stayed bridges in the world (**Fig. 4**).



*Fig.3 :Stromsund Bridge, Sweden First Cable Stayed Bridge*

It can be seen that 6 out of the top 10 cable stayed bridges are located in China. It can also be seen that the world record passed twice from steel orthotropic deck to a prestressed concrete deck and then to a composite deck. It is worth noting that the self weight of deck in case of CSB is very roughly in proportion of 1:2:3 for steel orthotropic to composite to prestressed concrete deck respectively [Ref-3]. Based on current data, it can be concluded that from economical considerations, the



*Fig.4 :Russky Bridge, Russia Longest Main Span CSB*

current limit for prestressed concrete deck is 500m-550m, about 700m for composite ones and beyond 700m, orthotropic deck must be adopted. In India, there are number of cable stayed bridges built in last two decades. The maximum main span length achieved is for Vidyasagar Setu, Kolkata, built in 1992 with a span length of 457m (**Fig. 5**). Other notable cable stayed bridges constructed are Worli-Bandra sea-link project, Mumbai; Yamuna bridge at Allahabad, UP; Akkar Bridge, Sikkim. Many more numbers of Cable Stayed Bridges in the span range of 300m-400m are presently under construction in India, including the much talked about signature bridge in Delhi (**Fig. 6**), but none in the span range to be in the list of top 10 in terms of maximum span length.

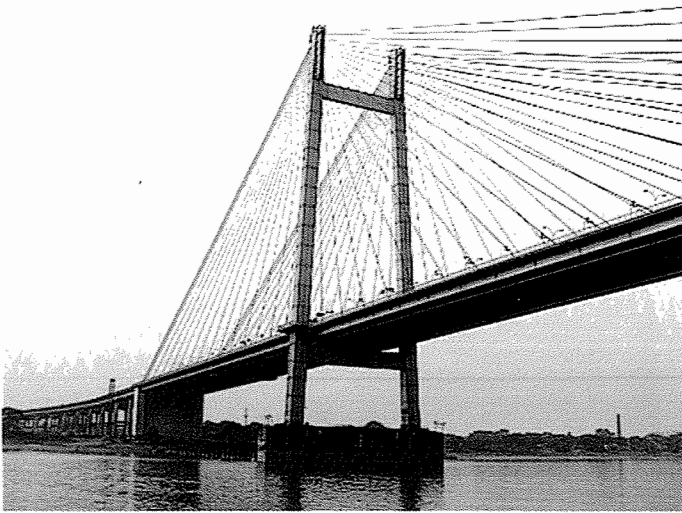


Fig.6 :Signature Bridge, Delhi

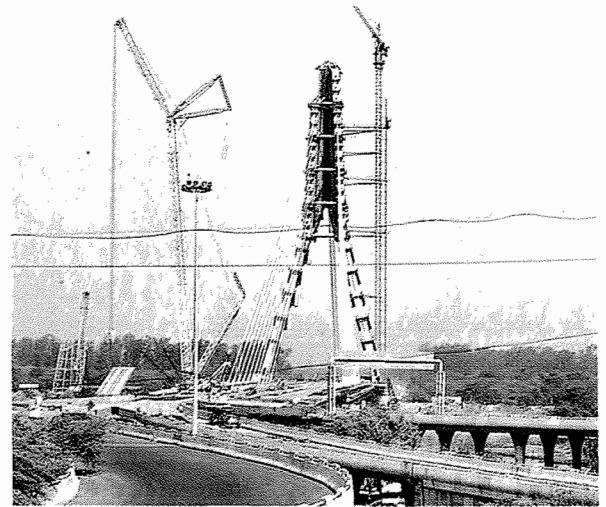


Fig.5 :VidyasagarSetu, Kolkata

**TABLE 2 : TOP 10 LONGEST SPAN CABLE STAYED BRIDGES IN THE WORLD<sup>[Ref-3]</sup>**

No.	Bridge Name	Span (m)	Deck Type	Country Located	Built Year
1	Russky	1104	Steel Orthotropic Deck	Russia	2012
2	Sutong	1088	Steel Orthotropic Deck	China	2008
3	Stonecutters	1018	Twin-steel box deck	Hongkong (China)	2009
4	Edong	926	PSC Box	China	2010
5	Tatara	890	Steel Orthotropic Deck	Japan	1999
6	Normandy	856	Steel Orthotropic Deck	France	1995
7	2 <sup>nd</sup> Jiujiang	818	Twin-box	China	2013
8	Jingyue	816	PSC Box	China	2010
9	Inchoen	800	steel/concrete composite deck	Korea	2009
<b>10</b>	<b>Xiazhang</b>	<b>780</b>	<b>steel/concrete composite deck</b>	<b>China</b>	<b>2009</b>

### 1.3 Multi-Span Cable Stayed Bridge

In a three span configuration of cable stayed bridge, the end piers, or anchor piers, and the end cables provide efficient support for the towers so that the bending moments in such a structure are very small. The loads are being carried mainly by axial forces in the girder, the towers and the cables. Such a structural system is very efficient and the structure can be designed to a very slender proportion. In a multi-span cable-stayed bridge, the beneficial effect of the anchor piers diminishes for intermediate spans, which are further away from the ends. This will require the interior towers to be sufficiently strong to resist

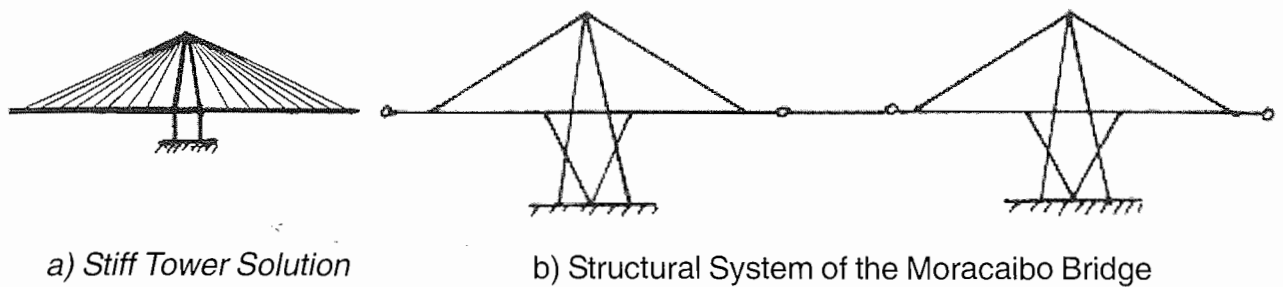
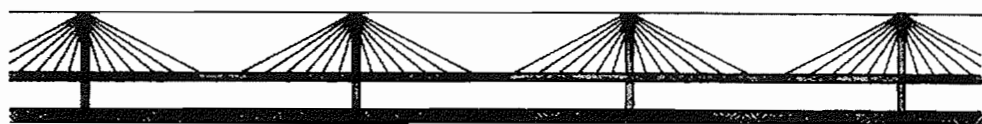


Fig. 7 : Structural Schemes for Multi-Span Cable Stayed Bridges

the entire unbalanced moment under a one-sided live load situation. Consequently the foundation becomes excessively costly. The bending moment in the girder is increased and the advantage of a cable-stayed bridge is lost. The most obvious solution to overcome the flexibility of a multi-span cable-stayed bridge is to provide very stiff towers. Dr Ulrich Finsterwalder, a famous German bridge engineer proposed such a solution for the Great Belt Bridge in Denmark<sup>[Ref-4]</sup>. Double piers were used at each tower to resist the large bending moment. Morandi used basically the same idea in the Maracaibo Bridge (Fig. 7). However, recent collapse of a cable-stayed Morandi Bridge in Genoa, Italy, in August 2018 has put a question mark on the Morandi system. Other solutions is to use a tie cable to tie the heads of the towers together. The tie cables work with the end cables at both ends of the bridge and the anchor piers to stabilize the towers (Fig. 8 (a)). The effectiveness of this system depends on the stiffness of the tie cable, the force in the tie cable and the length of the bridge. An alternative solution is to provide cross cables to connect the tower head to the girder at the adjacent towers (Fig. 8(b)). A new solution is evolved by adding additional cables at the midspans. These cables cross each other and extend for approximately 20% of span length beyond the span center (Fig. 8(c)). The advantage of such a solution is that it is efficient in reducing the bending moments in the girder and the towers to an acceptable level and still retains the slender look of a conventional cable-stayed bridge. Fig. 8 shows all these possibilities<sup>[Ref-4]</sup>.



(a) Head Cables



(b) Long cables from a pylon head to an adjacent pylon at the deck level



(c) Cable stays coming from both adjacent pylons to support the central part of each span.

Fig.8 :Hybrid Cable Stayed- Suspension Bridge Solution (HCS)

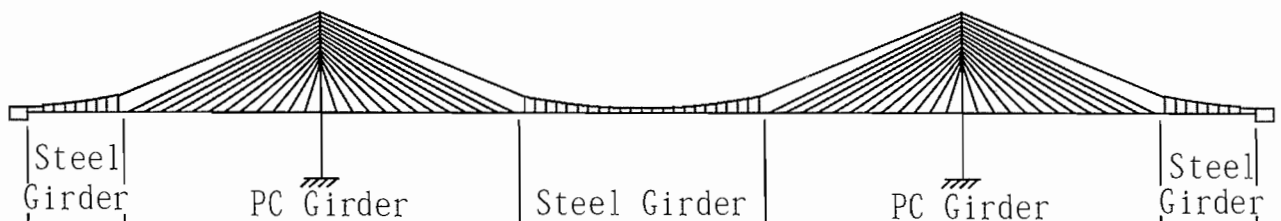
**Table 3** below gives the list of top 10 multi-span cable stayed bridges from different parts of the world. It can be seen that 5 out of the 10 longest multi-span cable stayed bridge is in China.

**TABLE 3 : TOP 10 LONGEST SPAN MULTISPAN CABLE STAYED BRIDGES IN THE WORLD<sup>[Ref-5]</sup>**

S. No.	Name	Year of Construction	Country	Main Span Length
1	Queensferry Crossing	2017	United Kingdom	650 m
2	Erqi Yangtze River Bridge	2011	China	616m
3	Rion-Antirion Bridge	2004	Greece	560m
4	Ting Kau Bridge	1998	China	475m
5	Jiashao Bridge	2013	China	428m
6	Yiling Yangtze River Bridge	2001	China	348m
7	Millau Viaduct	2004	France	342m
8	Mezcala Viaduct	1993	Mexico	311.5m
9	Mersey Gateway	2017	United Kingdom	300m
10	Ma'anshan Bridge	2013	China	260m

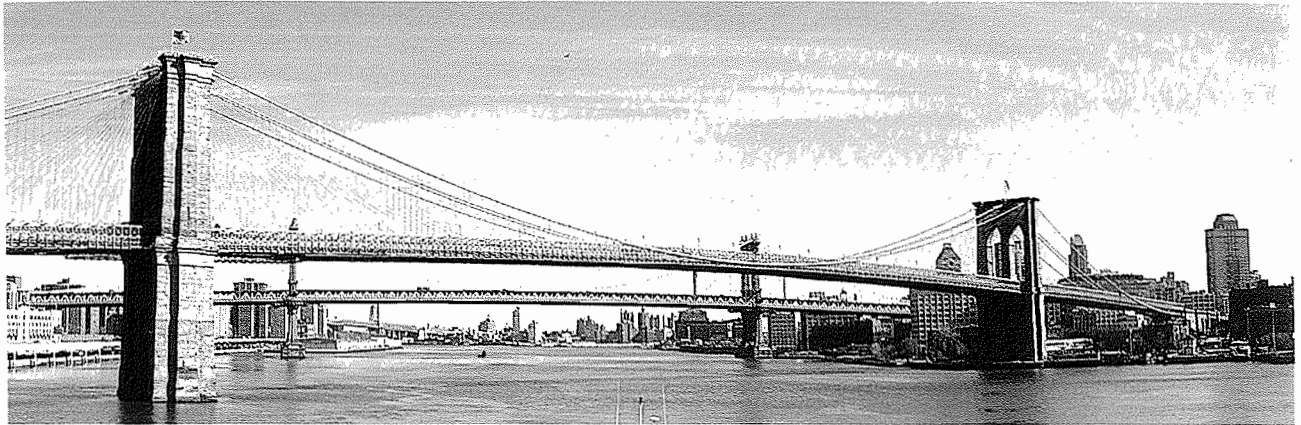
#### 1.4 Hybrid Cable Stayed – Suspension Bridge Solutions (HCS)

The hybrid system bridge has many structural features compared with ordinary cable-stayed bridge and suspension bridge. **Fig.9** shows concepts of the hybrid system bridge and ordinary cable supported bridges. In comparison with cable-stayed bridge, this system has better buckling stability and is applicable for longer span, because the axial force occurring in the girder can be reduced by decreasing the number of stay cables. Cable erection can be easier and cable vibration problems can be solved due to shorter stay cables. The height of pylons can be lowered by reducing the number of stay cables. In comparison with suspension bridge, this system has better aerodynamic stability, because the stay cables restrain the deformation of the girder. It is achieved to lessen the tension force occurring in the main cables, because the stay cables support more weight. And anchorage lateral force can be reduced.

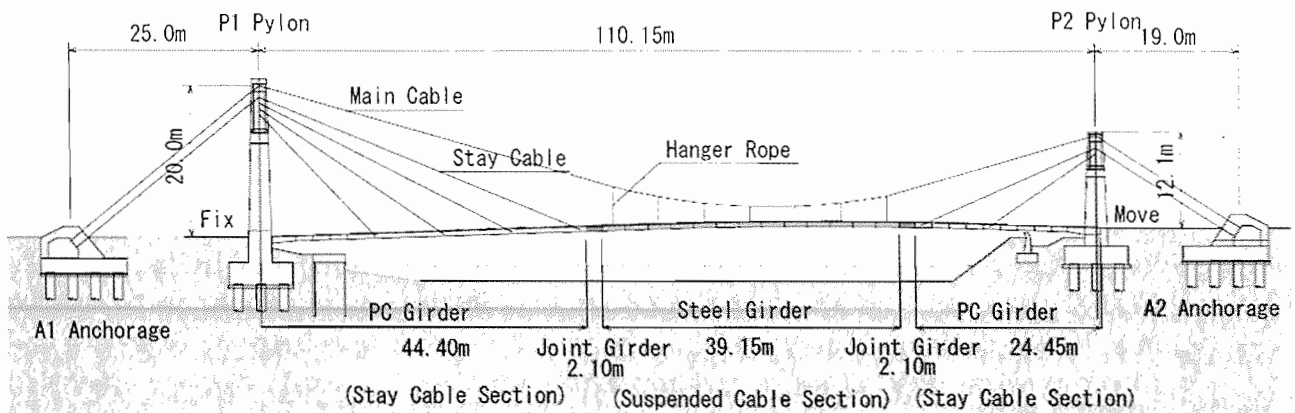


*Fig.9 :Hybrid Cable Stayed- Suspension Bridge Solution (HCS)*

With a combination of suspension bridge and cable stayed bridge concept, the span length can be extended beyond the range where cable stayed bridges rule. In 19<sup>th</sup> century, some bridges have been erected with a hybrid design concept (e.g. Brooklyn Bridge, New York, **Fig. 10**), constructed in 1883, with the main span of 486.3m, associating main suspension cables and hangers with stay cables in the areas close to the towers. This concept was abandoned in 20<sup>th</sup> century, with the concept of providing a stronger deck to provide the necessary rigidity.



*Fig.10 :Brooklyn Bridge, New York*



*Fig. 11 :General Arrangement of Nagisa Bridge, Japan*

In 21<sup>st</sup> century, we have seen revival of this concept. The first hybrid prestressed concrete cable stayed and steel cable suspension bridge in 21<sup>st</sup> century is Nagisa Bridge over river Nakamura, Japan (**Fig. 11**), which was completed in 2003<sup>[Ref-6]</sup>. Nagisa Bridge is a single span bridge with span of 110.15 m. The main girder is having depth of 0.7 m and a width of 7.0 m (effective width of 4.0 m). There are 2 pylons, and those heights are 20.0 m and 12.1 m respectively. A symbolic appearance was emphasized by making pylon height and cable arrangement asymmetrical. The pylons are composite structures of concrete members and steel shell members. Another HCS bridge which is worth a mention here is the Yavuz Sultan Selim Bridge (Popularly known as 3<sup>rd</sup> Bosphorus Bridge) in Turkey, constructed in 2013-2016, having main span length of 1408m (**Fig. 12**). The bridge is a combined road-rail bridge. It carries four motorway lanes and one railway line in each

direction. In a pure suspension bridge, the passage of heavy trains at quarter span would produce very large deflections, due to longitudinal displacement of the main cables, which will not be acceptable for the train traffic. The addition of stay cables produce the necessary rigidity.



*Fig. 12 :Yavuz Sultan Selim Bridge, Turkey*

### 1.5 Extradosed Bridges

The structural system of the Extradosed Bridges can be described as ‘in-between’ or ‘hybrid’ between balanced-cantilever-type box girder and cable-stayed bridges. In case of ED bridges, loads are shared between girder & Stays. Sharing depends on relative stiffness of deck vis-à-vis stay cable arrangement. There is a wide range therefore and not “one” narrowly defined form of Extradosed Bridge. Rather, there is a smooth transition from box girder to extradosed to cable-stayed bridges. In **Fig. 13**, the characteristics of the three bridges types mentioned above and principle difference in their salient dimensions are shown for comparison. Common design proportions for ED bridges are <sup>[Ref-7]</sup>:

- Main Span to Tower Height Ratio: 10:1
- Main Span to Girder Depth Ratio (at tower): 30:1
- Side Span to Main Span Ratio: 0.6:1

An important advantage of extradosed bridges is that they require a tower height much less than a cable stayed bridge in order to provide sufficient eccentricity of the cables for effective prestressing of the girder. This can result in significant simplification of construction and significant cost savings. ED bridges are generally suitable in the span range of 100m-250m. It is estimated that about 250 numbers of extradosed bridges are

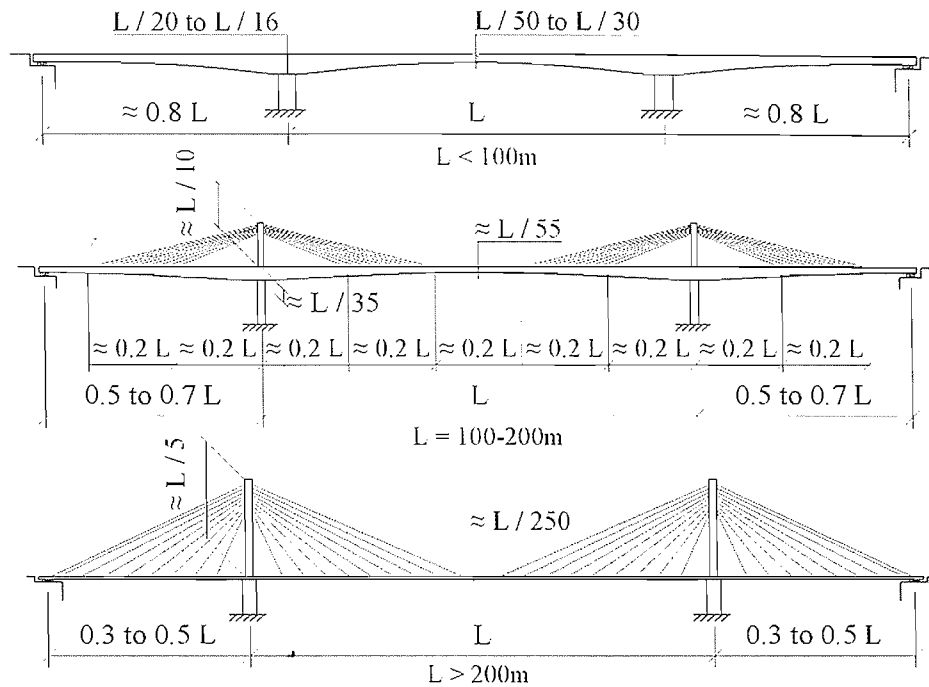


Fig. 13 :Comparison of Girder, Extradosed and Cable Stayed Bridge

already built around the world, spread over 29 countries. The number is fast increasing. China leads the numbers table with an estimated 85 bridges, followed by Japan with about 65 bridges. In India, there are estimated 21 numbers of extradosed bridges either constructed or under construction. **Table 4** below gives the list of Indian Extradosed Bridges for information. India's Veer Kunwar Singh Bridge over river Ganga, Bihar holds the record for longest extradosed bridge in the world, with bridge length of 1920m, with series of 120m spans (Span Arrangement : 60m+15x120m+60m) (**Fig. 14**). Wuhu Yangtze River Bridge, China holds the record for having world's longest main span for extradosed bridge category. The bridge consists of a 312 metres main span and two 180 metres side spans. It carries 4 lanes of highway traffic on the upper deck and the dual-track Huainan Railway on the lower deck (**Fig. 15**).

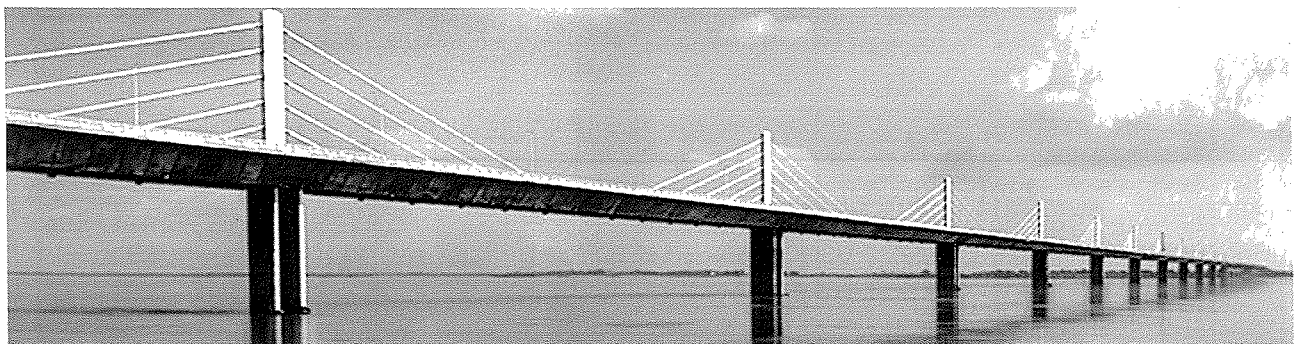
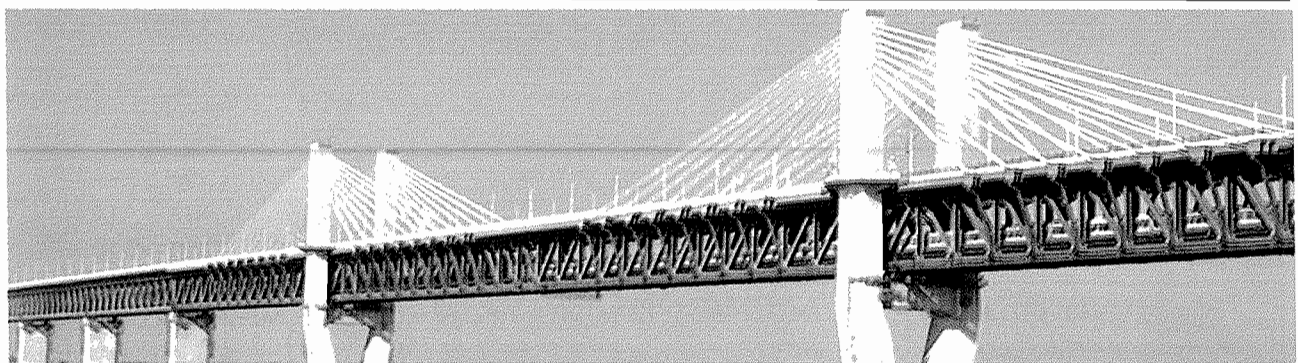


Fig. 14 :Veer Kunwar Singh Bridge over river Ganga, Bihar [Arrah-Chapra Bridge] (Longest Extradosed Bridge in World)

Sl. No.	Bridge Name	Year of Constn.	Type of Bridge	Total Bridge Length	Span Arrangement (For Extradosed Portion Only)
1	ROB for Metro at Pragati Maidan, New Delhi	2006	Railway	196.35	31m, 25m+93m+24m, 8m
2	Bridge at Siddapura, Karnataka	2006	Highway	56.00	1 X 56m
3	NiveditaSetu over river Hooghly at Kolkata	2006	Highway	880.00	55m+7x110m+55m
4	Metro Viaduct at Moolchand Crossing, New Delhi	2010	Railway	167.50	51m+61.5m+51m
5	Mumbai Metro - WEH Bridge, Mumbai	2013	Railway	175.00	2x23m+83m+2x23m
6	3rd Bridge over river Narmada at Bharuch, Gujarat	2016	Highway	1344.00	96m+8x144m+96m
7	Veer Kunwar Singh Setu over river Ganga connecting Arrah and Chhapra in Bihar.	2017	Highway	1900.00	60m+15x120m+60m
8	Bridge at Kamla Park in Bhopal, MP	2017	Highway	220.00	55m+110m+55m
9	B.P.mandal Bridge over river Koshi at Dumrighat, Bihar	2018	Highway	290.00	75m+140m+75m
10	2.544 Km Long Extradosed Bridge across river Ganga on NH-31 at Shri Rampur Ghat, Balia in UP State (in J.V)	2018	Highway	2544	(87m+144m+87m) X 8 Units
11	High Level Major Bridge on river Hatania-Doania West Bengal	Under Construction	Highway	340.00	85m+170m+85m
12	Bridge across river Ganga between Sultanganj & Aguwani Ghat Connecting NH 31 & NH80 in Bihar	Under Construction	Highway	3150.00	Unit-1 & 2 125m+2x162.5m+125m Unit-3 : 125m+1x162.5m+125m
13	Kacchi Dargah–Bidupur Bridge over river Ganges, connecting Kacchi Dargah and Bidupur, Bihar	Under Construction	Highway	9759.00	Modules of (75m+2x150m+75m)

14	Multi-sectional Interchange at Bailey Road between Lalit Bhawan and Patna High Court in Patna, Bridge SWAP-01	Under Construction	Highway	239.00	23m+50m+93m+50m+23m
15	Multi-sectional Interchange at Bailey Road between Lalit Bhawan and Patna High Court in Patna, Bridge SWAP-03	Under Construction	Highway	146.00	23m+50m+50m+23m
16	Bridge across river Hooghly at Kalyani, West Bengal	Under Construction	Highway	714.00	69m+102m+4x120m+63m
17	Bridge across Ganges on NH-31 Aunta-Simaria in the state of Bihar	Under Construction	Highway	1865.00	???
19	Keri Tiracol, Goa	Under Construction	Highway	350.00	70m+210m+70m
20	Bridge over Durgam Cheruvu Lake	Under Construction	Highway	365.00	96m+233.85m+96m
21	Barapullah Bridge over river Yamuna, New Delhi	Under Construction	Highway	552.50	85m+127.5mX3+ 85m



*Fig. 15 : Wuhu Yangtze River Bridge, China (Longest Main Span Length)*

The term 'extradosed' was coined first by Jacques Mathivat (1988) to appropriately describe an innovative cabling concept he developed in which external tendons were placed above the deck instead of within the cross-section, as would be the case in a girder bridge. However this concept was not executed in the bridge at that time. The first "real" Extradosed Bridge constructed was Odawara bridge [Fig. 16] in Japan, completed in 1994. It was built by a joint venture of Sumitomo Construction Company Ltd. and Kajima Corporation. Specific features of Extradosed Bridges cables are mentioned in several standards (such as fib 30 bulletin, PTI specification, SETRA specification). The significant fact for Extradosed Bridges cable is the low range of stress under live load. This fact has

consequences on axial resistances of stay cables. It impacts stress limits and fatigue limit states for main tension elements (i.e. cables). **Table 5** below gives the important difference between Girder Bridges, Extradosed Bridges and Cable Stayed Bridges in terms of stress variations and allowable service stress in stay cables. As the free length is limited, the Extradosed Bridges cable is less impacted by bending stresses at extremities due to angular deviation. The wind effects are less noticeable generally as mentioned above, with negligible vibrations.

### Odawara Port Bridge, Japan (1994)



Fig. 16 :First Extradosed Bridge constructed in Japan

**TABLE 5 :COMPARISON OF ALLOWABLE STRESSES BETWEEN GIRDER BRIDGE, EXTRADOSED BRIDGE AND CABLE STAYED BRIDGES** [Ref-7]

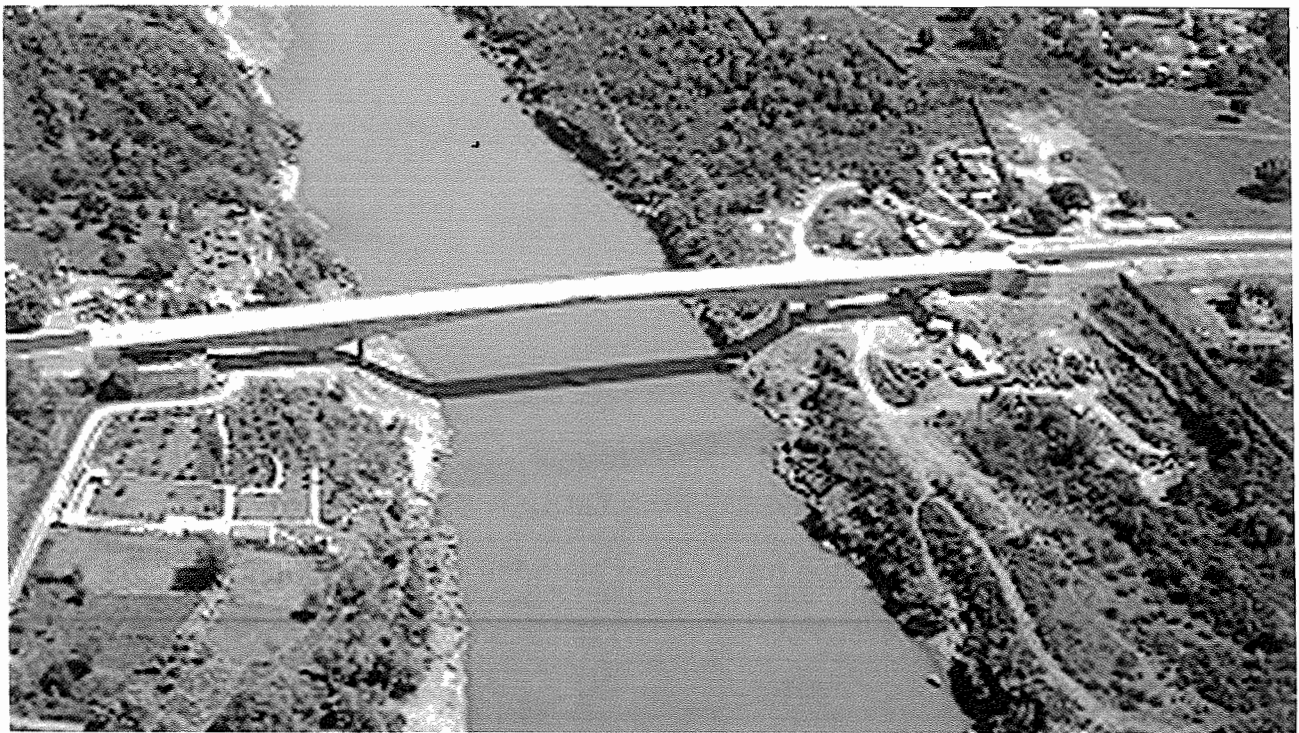
Parameter	Girder bridge	Extradosed bridge	Cable- stayed bridge
Stress variation under frequent live load	< 15 MPa	< 50 MPa	< 150 MPa
Fatigue test amplitude $D_s$	< 80 MPa	< 140 MPa	< 200 MPa
Allowable service stress in stay cable	70-80% GUTS	55-60% GUTS	45% GUTS
Type of anchorage	prestressing	Both systems can work	stay cable

### 1.6 Long Span Girder Bridges

Concrete Girder bridges of variable depth are most widely used bridge form in India amongst the category of 'Long Span Girder Bridges'. The longest span achieved in India till date is for Akhnoor Bridge (J&K), which is having an unbalanced cantilever design

with main span length of 160m and side spans of 60m on either side, which is anchored with the abutment by using vertical prestress (**Fig.17**). Continuous rigid frame bridges with deck monolithic with the substructure are quite common worldwide. Span length of this form of bridge developed as follows <sup>[Ref-8]</sup>:

- 208m Bendorf Bridge, Germany (1964)
- 260m Sir Leo Hielscher Bridge, Australia (1985)
- 270m Humen Bridge, China (1997)
- 301m Stolmasundet Bridge, Norway (1998)
- 330m 2<sup>nd</sup>Shibpano Bridge, China (2006)



*Fig. 17 :Longest Girder Bridge in India with Main Span of 160m*

The longest span girder bridge in China is a hybrid structure, where the central 108m of the main span is provided as a steel box girder, which is connected to concrete deck near supports. Use of steel box girder helped to save dead weight and thus increase span length to 330m (**Fig. 18**).List of top 10 longest span girder bridges completed are given in Table 6 below. It is interesting to note that 5 out of 10 longest span girder bridges are in China, followed by 3 in Norway and one each in Germany and Brazil. The bridges in Germany and Brazil are in steel, longest span is hybrid, while rest of the bridges are in prestressed concrete.



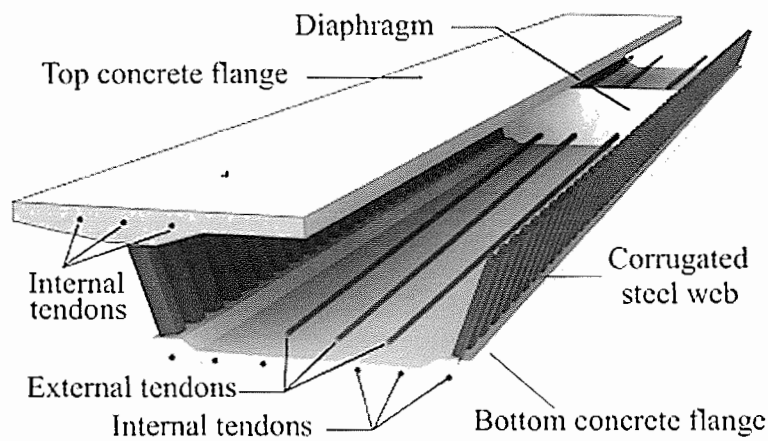
Fig. 18 :Shivanpo Bridge, China Longest Girder Bridge (330m)

**TABLE 6 :LIST OF 10 LONGEST SPAN GIRDER BRIDGES IN WORLD<sup>[Ref-8]</sup>**

No.	Bridge Name	Span [m]	Girder Material	Country Located	Built Year
1	2nd Shibanpo	330	Hybrid	China	2006
2	Stolmasundet	301	PC	Norway	1998
3	Costa e Silva	300	Steel	Brazil	1974
4	Raftsundet	298	PC	Norway	1998
5	Sundoy	298	PC	Norway	2003
6	Beipanjiang	290	PC	China	2012
7	Humen Secondary	270	PC	China	1997
8	Sutong Secondary	268	PC	China	2008
9	Honghe	265	PC	China	2003
10	Neckartalbrücke-1	263	Steel	Germany	1978

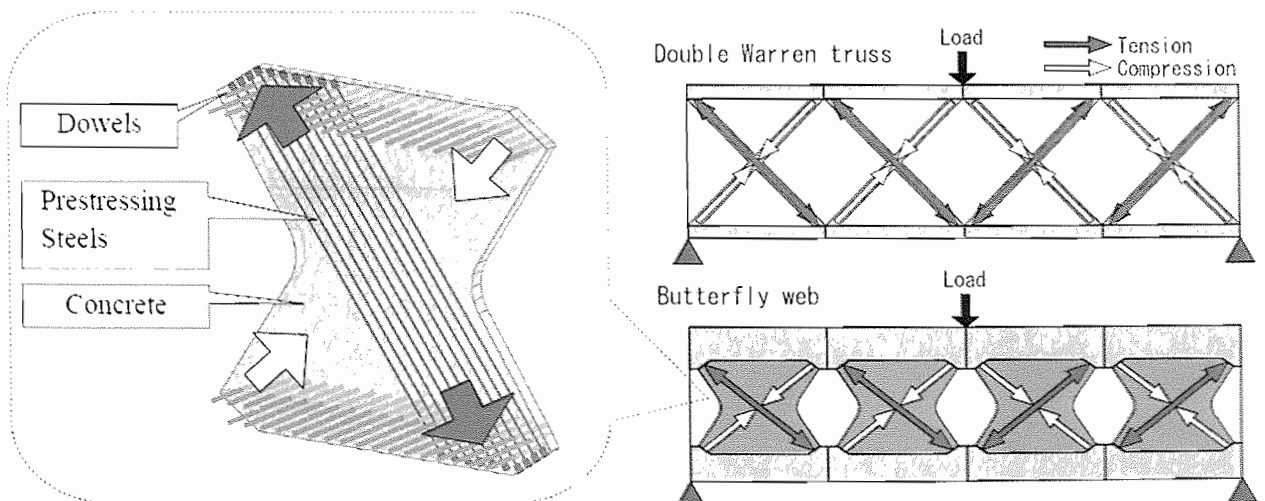
Fig. 19 : Typical corrugated-steel-web box-girder bridge

There are several issues and challenges for this type of Bridges, which comes in the way of increasing the span length beyond a certain limit. Firstly, major loads in case of long span girder bridge is the dead load of structure, which is a problem for substructure and foundation design, particularly in earthquake prone areas. Some of the methods to reduce dead load, adopted widely in Japan and China is to use corrugated Steel Web bridges (**Fig.19**). In China, there are more than 100 PSC box girder bridges, built with corrugated steel webs since 2005 when the first bridge was built. Japan has constructed over 300 bridges of this kind. However, the composite structure of steel components and of their joints with the concrete in these bridges produces a requirement for special machining technology and for on-site welding. Also, such bridges require regular maintenance to keep durability of the structure during their design lifetime.



*Fig. 19 : Typical corrugated-steel-web box-girder bridge*

Another type of structure used to reduce the dead weight is called “Butterfly Web Bridges”<sup>[Ref-9]</sup>. The butterfly web structure uses butterfly-shaped panels in the web. With respect to shear force acting on the web, it behaves similarly to a double Warren truss structure (**Fig. 20**).



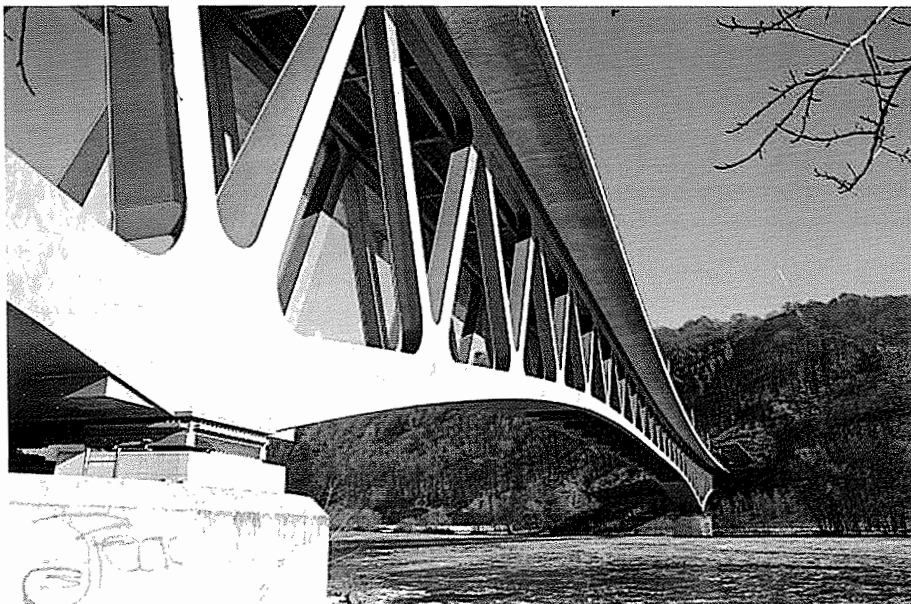
*Fig. 20 : Structural properties of Butterfly webs*

The Takubogawa Bridge, Japan is the world's first to use a butterfly web structure with butterflyshapedconcrete panels utilized in the web of the main girder as a means for erecting thebridge more efficiently and for reducing construction cost (**Fig. 21**). The bridge is 712.5m long with span arrangement : 58.6m+87.5m+7x73.5m+49.2m.



*Fig. 21 :Tukubogawa Bridge, Japan*

The third method to reduce dead weight adopted in recent times, is the use of composite trusses mainly adopting tubular members. Use of Composite truss bridge improves aesthetical qualities related to lightness and transparency; has better rating for sustainability. This is in addition to other structural advantages due to reduced dead weight. Nantenbach Railroad Bridge (Germany) is the first bridge constructed in this category in the year 1993 (**Fig. 22**).

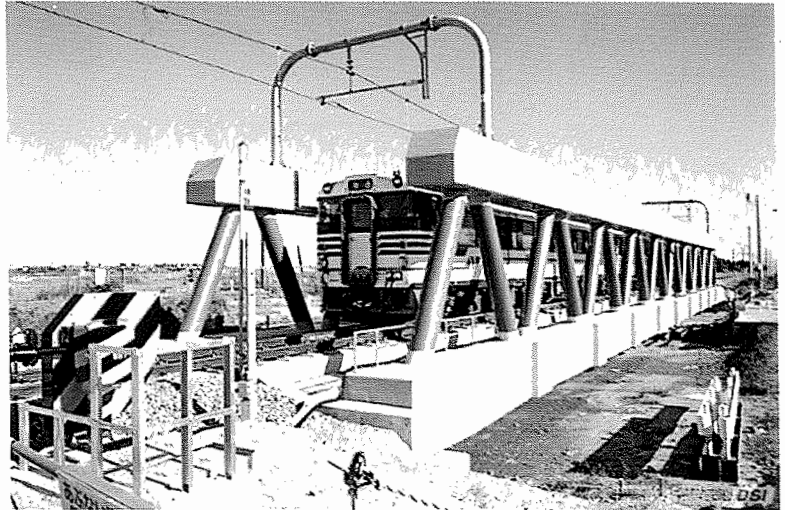


*Fig. 22 :Nantenbach Railroad Bridge, Germany*

The concept has been used subsequently in several bridges, using circular hollow tubular sections (CHS), in Germany, France, Switzerland, Japan and China. Lully viaduct in Switzerland, is a fine example of optimum use of the structural steel material in bridges. The 1 Km long Lully viaduct proposes a light and transparent structure made of a triangular cross-section fabricated entirely from unstiffened circular tubes. The result is twin space trusses, with a typical span of 42.75 m (**Fig. 23**). First prestressed composite railway bridge in Japan with steel pipe truss webs is Yamaguragawa Bridge, Japan. It is a post-tensioned concrete trough bridge characterised by girders with steel pipe truss webs. It is the first composite railway bridge that combines the benefits of steel and concrete to achieve higher structural efficiency (**Fig. 24**). The bridge is a 51.8 m long, 6.75 m wide single-span structure. Since the bridge is located in a snowy area, the bottom slabs were designed as a grid structure, to facilitate snow removal.



*Fig. 23 :The Lully Viaduct, Switzerland*



*Fig. 24 :Yamaguragawa Bridge, Japan*

### 1.7 Arch Bridges

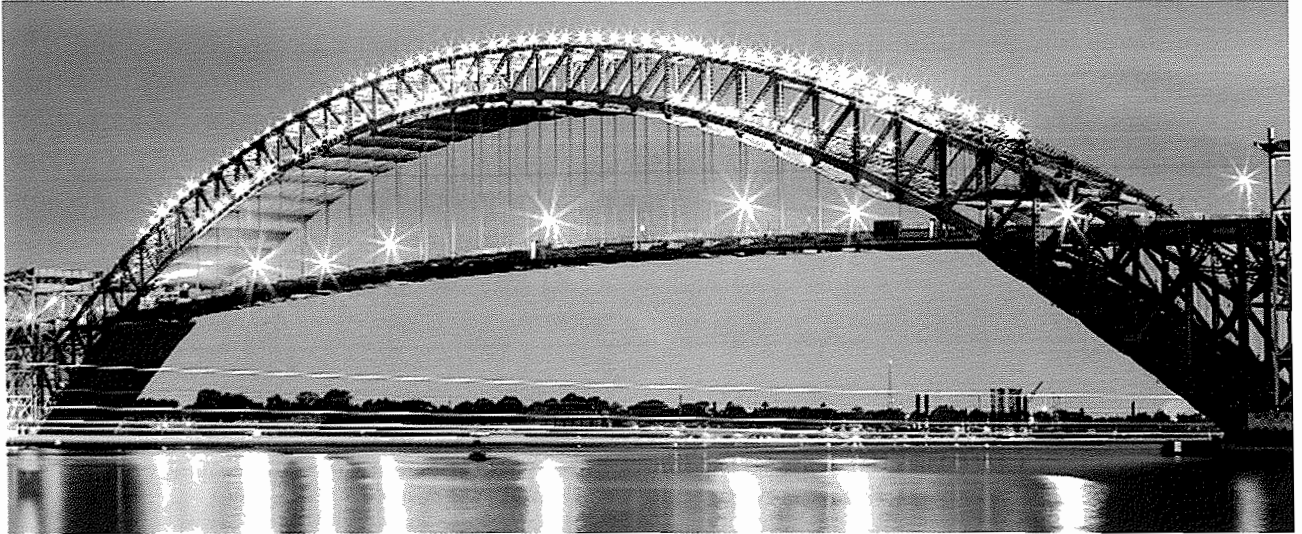
Arch bridge is an ancient bridge type originated from stone arch, which was firstly invented around 2,500 BC in the ancient Greeks, and developed most fully for bridges by the ancient Romans. Possibly the oldest existing arch bridge is the Mycenaean Arkadik bridge in Greece from about 1300 BC, which is still in use (**Fig. 25**).



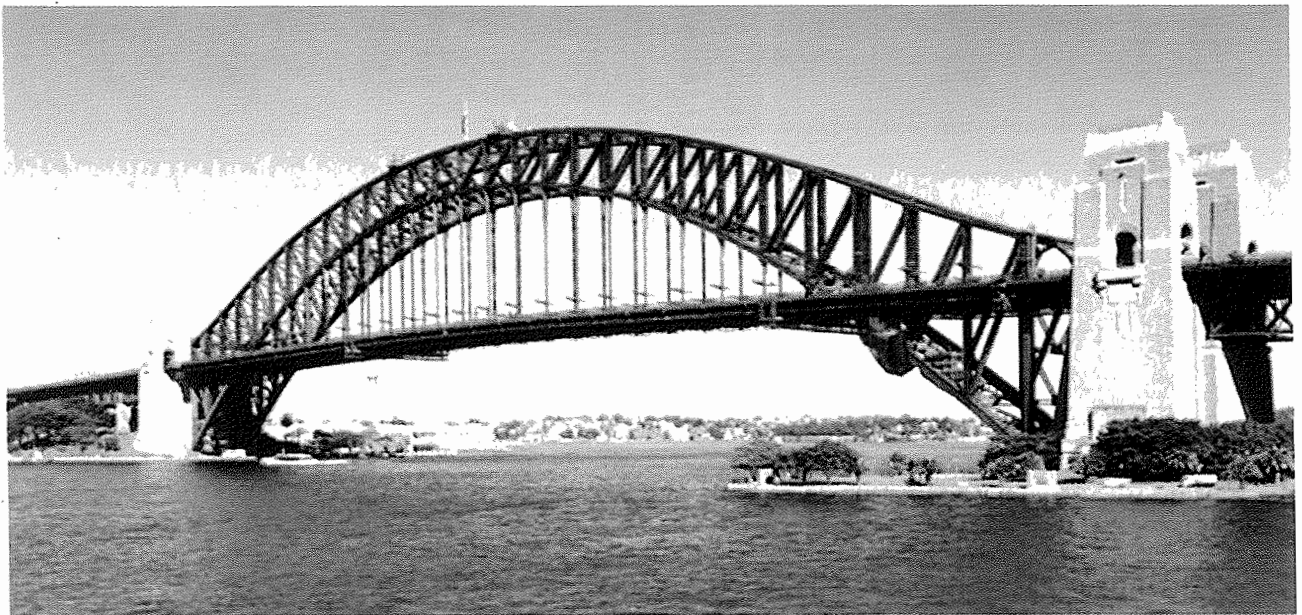
*Fig. 25 :Arkadiko Mycenaean Bridge, Greece*

China has an ancient history of arch bridge construction for about 2,000 years, and the oldest existing bridge is Zhaozhou Bridge of 605AD, which is the world's first wholly-stone open span and resegmental arch

bridge. In the moderntime of 1930's, two famous long-span arch bridgeswere completed, namely the 504m BayonneBridge in the United States (**Fig. 26**) and the 503m SydneyHarbour Bridge in Australia (**Fig. 27**), which had become the longest arches for about 45 years, till theemergence of West Virginia's518m New River Gorge bridge of USA in1977, connecting the hills on either side (**Fig. 28**).



*Fig. 26 :Bayonne Bridge, NJ, USA (504m)*



*Fig. 27 :Sydney Harbour Bridge, Australia (503m)*

In the last 13 years, China has built several remarkable arch bridges with very long spans, including seven arch bridges among the top ten longest span arch bridges in the world that exists today and listed in **Table 7**. It can be seen from the table that China has kept almost all span length records for arch bridges, including 530m span Bosideng Bridge with concrete-filled steel tube arch ribs, 550m span Lupu Bridge with steel box arch ribs

and the world record holder 552m long trussed Chaotianmen Yangtze River Bridge(**Fig. 29**).

India is currently constructing the 469m long steel arch bridge over river Chenab, which is expected to be the world's tallest arch bridge by the time it is completed. It is being built at a height of 359m above the river bed(**Fig. 30**). This railway bridge carrying 2 railway tracks, is going to be a landmark in India, which is located between Bakkal and Kauri in the Reasi district of Jammu and Kashmir. It is a part of Jammu-Udhampur-Srinagar-Baramulla Rail Line (JUSBRL) project being undertaken by Ministry of Railways.

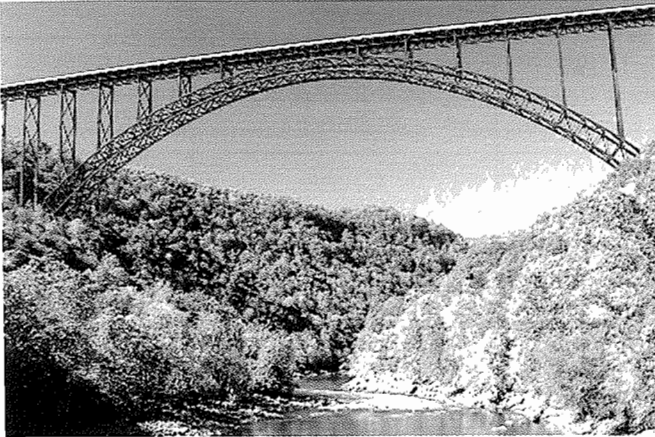
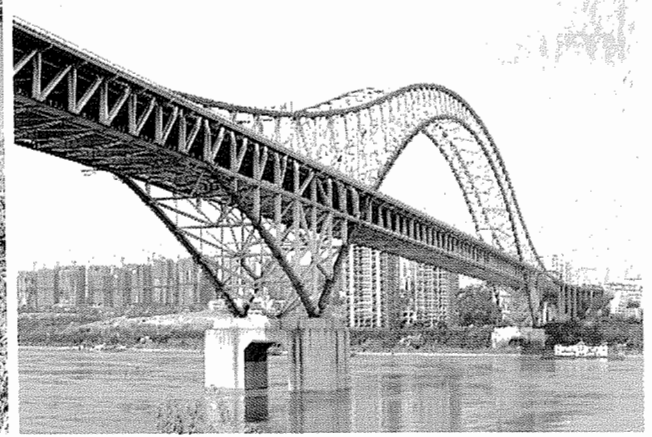


Fig. 28 :New River George Bridge,  
USA (518m) Fig.



29 :Chaotianmen Yangtze river  
Bridge, China



Fig. 30 :Chenab Bridge, J&K (Under Construction), India

**TABLE 7 :LIST OF 10 LONGEST SPAN ARCH BRIDGES IN WORLD<sup>[Ref-8]</sup>**

No.	Bridge Name	Span (m)	Arch Ribs	Country Located	Built Year
1	Chaotianmen	552	Truss	China	2009
2	Lupu	550	Box	China	2003
3	Bosideng	530	CFST	China	2012
4	New River Gorge	518	Truss	USA	1977
5	Bayonne	510	Truss	USA	1931
6	Sydney Harbour	503	Truss	Australia	1932
7	Wushan	460	CFST	China	2005
8	Mingzhou	450	Box	China	2011
9	ZhaoqingXijiang	450	Box	China	2013
10	Zhijinghe	430	CFST	China	2009

## 2. Evolution of bridge span lengths in India and the Way Forward

We have seen in the above section that with the scientific and technological developments, bridge engineers worldwide have kept on increasing the bridge span lengths in all bridge types. Also new bridge types have emerged. With longer spans, bridge engineering becomes more and more challenging in statics, dynamics and aerodynamics, and bridge engineers have to overcome challenging difficulties with innovative technology to reach longer span lengths. Records of top ten long span bridges around the world in several bridge types is a yardstick to measure the technological development and progress made by the country in the field of bridge engineering (in terms of research, manufacture, production, design as well as construction skills). The records in the previous section have clearly shown the very fast progress that has been made by China in last 15-20 years in this direction and they have taken a dominant position in this field.

India's records so far are unfortunately not very encouraging and it appears that we are making progress at a very slow pace in this regard, though large-scale construction and infrastructure development is taking place in the country. It is not that in India, we do not have the demand for super long span bridges, but it is just that we are trying to fit in a moderate span length which matches with the available technology and skill in the country, thus leaving out the opportunities to build difficult bridges. The reason why in India we need to build more and more super long span bridges, surpassing the existing record spans in all bridge types is the following :

- a) Need to be at par with the progress in materials and technology worldwide. Building of long span bridges helps to bring in this new materials and technology in the country.
- b) Design and construction of super long span bridges will bring in greater use of the information technology in the design, which will help developing the design skills of the Indian Consultants and Contractors, allowing for complex computations.

a) The design of super-long span bridges is mostly governed by wind effects. It calls for streamlined decks, for aerodynamic stability, but also to reduce the effects of turbulent winds to which the bridge has to resist. Cross section of such bridge decks and pylon shapes / sizes are very much decided based on wind tunnel testing of the structural models. Going for more and more such bridges will help us develop our research and testing facilities. This will help us to close the technological gap with the developed countries much faster, with a much better understanding and knowledge of natural forces.

b) Most importantly, this will help us to go for sustainable development, where material will be optimally utilised.

### 3. Closing Remarks

Long Span Bridge is a vast subject and due to limited space, the author could not cover the subject in entirety. There are several issues which are important for the planning, conceptualisation, design, construction and maintenance of modern day long span bridges. Issue of appropriate live load for long span bridges, stay cable technology, testing and acceptance criteria for stay cables, evolving appropriate project specifications which are upto date with the latest research and experience worldwide are not adequately covered in this paper. Never the less, the author hopes that he has been able to give a broad canvass about the long span bridges around the world to the readers.

The author is confident that such bridges will have a wide field of application in the Indian sub-continent in future to serve the needs of the society in a sustainable manner.

### REFERENCES

1. [https://en.wikipedia.org/wiki/Jacob%27s\\_Creek\\_Bridge\\_\(Pennsylvania\)](https://en.wikipedia.org/wiki/Jacob%27s_Creek_Bridge_(Pennsylvania))
2. [https://en.wikipedia.org/wiki/List\\_of\\_longest\\_suspension\\_bridge\\_spans](https://en.wikipedia.org/wiki/List_of_longest_suspension_bridge_spans)
3. Michel Virlogeux: Long Span Bridges, published in 40th IABSE Symposium on 'Tomorrow's Mega-structure', September 2018, Nantes, France.
4. Man-Chung Tang : 'Multispan Cable Stayed Bridges', IABSE Congress Report, 1996
5. <https://structurae.net/structures/bridges-and-viaducts/multiple-span-cable-stayed-bridges>
6. Yuzuru Sato, Shinichi Sasaki, Katsutoshi Morohashi, Nobumasa Suzuki : CONSTRUCTION OF NAGISA BRIDGE - HYBRID SYSTEM OF CABLE-STAYED PC BRIDGE AND STEEL SUSPENSION BRIDGE
7. IABSE - Working Commission 3: 'Extradosed Bridges - State-of-the-Art-Report' ..Draft report submitted to IABSE editorial Board.
8. Yaojun Ge: Challenge and Innovation of Long Span Bridges in China and Over the World, published in 39<sup>th</sup> IABSE Symposium on 'Engineering the Future', September 2017, Vancouver, Canada.
9. Kenichi Kata, Kenichiro Ashizuka, Kenji Miyamoto, Kenichi Nakatsumi : 'Design and Construction of Butterfly Web Bridge', Third International Conference on Sustainable Construction Materials and Technologies, August 18 – August 21 2013, Kyoto Research Park, Kyoto, Japan

### **About the Author**

*Shri Alok Bhowmick is an eminent structural engineer with nearly four decades of experience in the profession of bridge and structural engineering. He is proactively involved through various institutions and with colleagues, peers and the structural engineering fraternity to disseminate knowledge for capacity building of the young engineers and to cultivate a culture of excellence in their respective workplaces. He is the recipient of "24<sup>th</sup> S B Joshi Memorial Award for Excellence in Bridge and Structural Engineering", conferred to him this year in October.*

*Shri Bhowmick is involved aggressively in the development of modern set of codes for highway transportation sector through active participation in several code committees of Indian Roads Congress.*

*Shri Bhowmick is an active member of many professional bodies and learned societies. Besides being a Fellow and Honorary Secretary of Indian Association of Structural Engineers (IAStructE), he is also a member of National Governing Council of Consulting Engineers Association of India (CEAI) and Vice Chairman of the Indian National Group of International Association of Bridge and Structural Engineers (ING-IABSE). He is the Chairman of the Editorial Board of ING-IABSE since 2013 and has been instrumental in bringing out qualitative changes in this journal. Further, he is active in many professional bodies like Indian Roads Congress, Institution of Engineers (India), Indian Geotechnical Society and fib.*