Juhani Virola

Two long-span suspension bridges of the past and new millennia

In this article, 2 long-span suspension bridges are described: the Akashi-Kaikyo Bridge in Japan, re: articles [1] and [2], and the Runyang South Bridge in China, [12] and [13]. The Akashi Bridge is dated 1998. With its main span of 1991 m, it is the longest-span bridge ever built and the greatest bridge of the past Millennium. The Runyang Bridge (1490 m) was commenced in 2000 and is due for completion in 2005. Then it will the 3rd longest-span bridge ever built, and the greatest bridge in the beginning of the new Millennium. As an example, another bridge type is briefly mentioned. It is the Tsukuhara Bridge [3], located in Honshu island, a few kilometres away from the Akashi Bridge. The Tsukuhara Bridge consists of 2 adjacent bridges, at completion in 1998 the longest-span (180 m) "extradosed prestressed concrete bridge" in the world. Soon thereafter, however, some longer-span such bridges were built in the world. To mention 2 such bridges in Japan: the Kiso Bridge (3 x 275 m main spans) and the Ibi Bridge (4 x 271,5 m), [4].

Passato e nuovo millennio: i due ponti sospesi di grande luce

Nell'articolo vengono descritti due ponti sospesi di grande luce: l'Akashi-Kaykyo Bridge in Giappone [1] e [2] e il Runyang South Bridge in Cina [12] e [13]. Il ponte Akashi è stato costruito nel 1998. Con la sua campata principale di 1991 m è il più lungo ponte mai costruito ed è il più grande del passato millennio. La costruzione del ponte Runyang (1490 m) è iniziata nell'anno 2000 e il suo completamento è previsto per il 2005. Questo ponte sarà il terzo in classifica per lunghezza di campata, nonché il più grande dall'inizio del nuovo millennio. Viene inoltre brevemente citato, a titolo di esempio, un altro tipo di ponte; si tratta dello Tsukuhara Bridge [3], localizzato nell'isola di Honshu, a pochi chilometri di distanza dell'Akashi Bridge. Il ponte Tsukuhara consiste in due ponti adiacenti che al momento del completamento, nel 1998, risultavano avere la più lunga campata del mondo presollecitata all'estradosso. Meritano ancora una menzione altri due ponti di grande luce costruiti nel mondo: i due ponti giapponesi: Kiso Bridge (3x275 m di campata principale) l'Ibi Bridge (4x271,5 m) [4].

THE AKASHI-KAIKYO BRIDGE, GREATEST BRIDGE OF THE PAST MILLENNIUM

Fixed links between Japanese main islands

The area of Japan is 378.000 km^2 and the population is about 126 million (in 1998). Japan consists of 4 main islands. These are from south-west to north-east: Kyushu, Shikoku, Honshu, Hokkaido.

Between Kyushu and Honshu there are tunnel and bridge links. The Kanmon Strait Bridge between Kyushu and Honshu is a notable suspension bridge, main span 712 m, longest-span bridge in Asia at completion in 1973.

Between Kyushu and Shikoku there are not yet fixed connections.

Plans for a fixed link between Kyushu and Shikoku and also for some other long-span bridges in Japan are under consideration [5].

Between Honshu and Hokkaido under the Tsugaru Strait, the Seikan Tunnel was completed in the 1980's. With a length of nearly 54 km (53 km 850 m) it is the world's longest railway tunnel: the Eurotunnel under the English Channel is about 50 km in length.

Between Honshu and Shikoku, there are existing 3 fixed links, from east to west: Kobe-Naruto, Kojima-Sakaide, and Onomichi-Imabari.

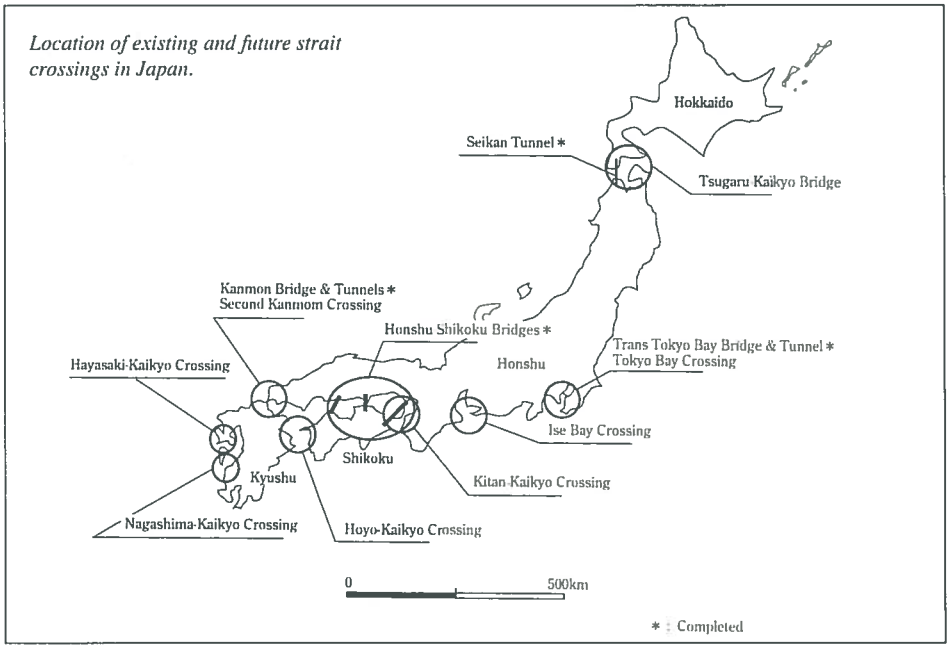
These routes contain several great bridges, some of those world record bridges. The easternmost link is the Kobe-Naruto route, west of Osaka, length 89,0 km, completed in Spring 1998. Its most remarkable structure is the Akashi-Kaikyo Bridge, the longest-span (1991 m) bridge in the world.

Of these 3 links, only the middle one or the Kojima-Sakaide route (length 37,3 km) conveys both road and rail traffic, while the 2 other routes convey only road traffic. The Kojima-Sakaide route is located some 100 km west of Kobe and it was completed in Apr.1988.

It contains notable suspension and cable-stayed bridges. This bridge combination is known also as the Seto-Ohashi Bridge. Its most remarkable structure is the Minami Bisan-seto suspension bridge, main span 1100 m, until 1997 the world's longest-span bridge for road/rail traffic. The overall length of the Seto-Ohashi Bridge is 12 km 306 m, the longest road/rail bridge in the world.

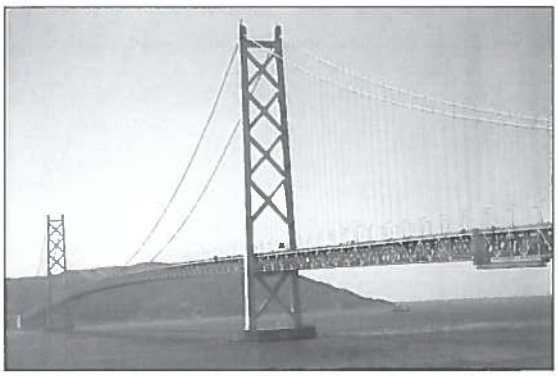
The westernmost Honshu-Shikoku fixed link is the Onomichi-Imabari route, length 59,4 km, completed in May 1999.

Location of existing and future strait crossings in Japan.



No.	Bridge	Span	Location	Year
1	Akashi-Kaikyo	1991 m	Kobe-Naruto, Japan	1998
2	Great Belt East	1624 m	Korsør, Denmark	1998
3	Runyang South	1490 m	Zhenjiang-Yangzhou, China	2005
4	Humber	1410 m	Kingston-upon-Hull, UK	1981
5	Jiangyin	1385 m	Jiangsu, China	1999
6	Tsing Ma	1377 m	Hong Kong, China	1997
7	Verrazano-Narrows	1298 m	New York, NY, USA	1964
8	Golden Gate	1280 m	San Francisco, CA, USA	1937
9	Höga Kusten	1210 m	Kramfors, Sweden	1997
10	Mackinac	1158 m	Mackinaw City, MI, USA	1957
11	Minami Bisan-seto	1100 m	Kojima-Sakaide, Japan	1988
12	Fatih Sultan Mehmet	1090 m	Istanbul, Turkey	1988
13	Bosporus	1074 m	Istanbul, Turkey	1973
14	George Washington	1067 m	New York, NY, USA	1931
15	Kurushima-3	1030 m	Onomichi-Imabari, Japan	1999
16	Kurushima-2	1020 m	Onomichi-Imabari, Japan	1999
17	Ponte 25 de Abril	1013 m	Lisbon, Portugal	1966
18	Forth Road	1006 m	Edinburgh, UK	1964

The world's longest-span bridges by the year 2005 (span >1000 m) all of these are suspension bridges



Akashi-Kaikyo Bridge, the longest-span bridge in the world. Photo taken from the Maiko Tower, near the north anchorage (Kobe side). (Photo: Leena Virola)

Tsukuhara Twin Bridge, at completion in 1998 the longest-span (180 m) extradosed prestressed concrete bridge in the world, near Kobe, Japan. (Photo: Leena Virola)

It is situated some 200 west of Kobe, and it also contains a number of great bridges.

Internationally the most remarkable of those is the Tatara Bridge, the world's longest-span (890 m) cable-stayed bridge.

Another notable bridge is the Kurushima-Kaikyo Bridge. It is a unique combination of 3 successive suspension bridges, 6 towers, 4 anchorages, main spans 1030 + 1020 + 600 m, and total length 4015 m including the side spans. This 4015 m is a record: it is the world's longest suspension bridge structure, longer than the suspension bridge structure of the Akashi Bridge, which is 960 + 1991 + 960 m = 3911 m.

The total length of these 3 Honshu-Shikoku routes is about 186 km (about the same as the railway connection between Helsinki and Tampere in Finland). The construction was commenced in the 1970's, and the total cost is about JPY 3400 milliard (3.400.000.000.000).

History of the Akashi Bridge

On the Kobe-Naruto route, a smaller Awaji Island is located between Honshu ja Shikoku. The 4 km wide Akashi Strait is located between Awaji and Honshu. The Akashi-Kaikyo Bridge is named thereby: Japanese word "Kaikyo" means "Strait" in English. The bridge across the Akashi Strait is located some tens of kilometres west Kobe, which itself is west of Osaka. Heavy sea traffic along the Akashi Strait (some 1400 ships a day) dictates a long main span for the bridge [5]. The max. current speed in the strait is 4,5 m/s.

On the same Kobe-Naruto route, south of the Akashi Strait and between Awaji and Shikoku islands, the Ohnaruto Bridge was completed in 1985. It is a suspension bridge, main span 876 m.

The Akashi Bridge was first proposed in the 1950's. The main span was all the time increasing. In the 1960's, the main span was considered to be 1300-1500 m, a world record in those times [6]. In the 1970's, the main span was increased to 1780 m and the bridge was proposed for both road and rail traffic. In 1985, the rail alternative was abandoned and a decision was made to restrict the bridge for highway use only. According to careful consideration (i.a. heavy sea traffic, difficult foundation conditions), the optimal main span range appeared to be 1950-2050 m.

The final main span was to be 1990 m, annoyingly less than the magic 2 km mark.

Even this exceeds by 41% the previous record: Humber Bridge in Britain, main span 1410 m, dated 1981.

Construction of the Akashi Bridge was commenced in May 1988, and the construction period lasted 10 years. Of its type the bridge is a 3-span 2-hinged suspension bridge with steel truss stiffening girders for deck structure, designed spans 960 + 1990 + 960 m = 3910 m, actual spans somewhat longer. The bridge is located between Maiko (in Shikoku) in the north and Matsuho (in Awaji) in the south. At each end there is a short viaduct made of concrete.

It should be mentioned that actually this suspension bridge length of nearly 4 km is roughly only 10 % of the longest bridge in the world. That record belongs to the Second Lake Pontchartrain Causeway, in Louisiana, U.S.A., dated 1969. It is a multi-span bridge, total length 38 km 422 m, while its spans are only about 25 m on an average. So the Akashi Bridge is the world's longest-span bridge. But it is definitely not the longest bridge in the world, though this impression might be given in some sources, for instance in the title of the reference [5].

The main span of the Akashi Bridge is the first ever exceeding the English mile (1609 m), and currently the only one exceeding even the nautical mile (1852 m). With a full reason it may be said that in many respects this is the most remarkable bridge of the past millennium. During the new millennium, some longer-span bridges may be built. To mention some of the proposed gigantic bridges of the future:

- across the Messina Strait between Sicily and mainland Italy: a suspension bridge, main span 3,3 km.
- across the Tsugaru Strait in Japan: a hybrid su-

spension/ cable-stayed bridge with 2 successive main spans of 4 km [7]
- across the Gibraltar Strait between Spain and Morocco: a suspension bridge with 2 successive main spans of 5 km, or a cable-stayed bridge with an enormous main span of 8,4 km [8].

Foundations and towers

The huge cable anchorages (anchor blocks), made of concrete, are located on both shores. To prevent the corrosion of the cable wires, the relative humidity of the air inside anchorages is kept at max. 60%, practically about 40% [9].

The both towers, located in the sea, are founded on large caissons 80 m in diameter, foundation depth about 70 m below water level, which is near a record. Among long-span bridges (>1000 m), the south tower of the the Ponte 25 de Abril in Lisbon has the world's deepest foundation depth below water level (80 m).

The towers of the Akashi Bridge are made of steel, height above the piers 283 m, 297 m measured from water level. These are the tallest bridge towers in the world. Due to the curvature of the earth surface, the distance between the towers is 93 mm longer at top than at base. Among long-span suspension bridges (>1000 m), the majority of bridges has steel towers. Some bridges have concrete towers, like Great Belt, Runyang (1490 m; dt. 2005), Humber, Jiangyin, Tsing Ma, Höga Kusten: mainly bridges in Europe and China.

Main cables and hangers

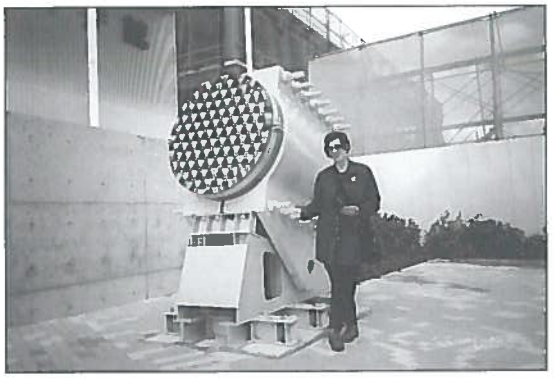
The Akashi Bridge has 2 main cables, each 1122 mm in diameter, a world record. Each cable consists of 290 parallel-wire ropes, each containing 127 high-strength wires 5,23 mm in diameter. Thus each cable contains 36.830 parallel wires, the total length of those being about 300.000 km. The wires are of special high-strength grade, ultimate tensile strength 1800 MPa (180 kgf/mm^2). Thus only 2 main cables are needed, while the previous grade 1600 MPa would need 4 main cables. The 10 mm-diameter poly-aramid fiber pilot rope was carried across the strait by helicopter, a method first time used for a major suspension bridge. The wires of the cables are protected carefully against corrosion. Also the atmosphere environment inside the cables is improved by injecting dried air into the cables [9].

With the majority of long-span suspension bridges (>1000 m), the main cables are built using the conventional AS-method (Air Spinning), used since the late 1800's. In that technique, a few parallel continous steel wires are hauled with special reels at a time between the anchor blocks.

In the modern PPWS technique (Prefabricated Parallel Wire Strands) the cables consist of shop-fabricated parallel-wire strands [10].

This technique is applied in the Akashi Bridge and in some other long-span suspension bridges in Japan (e.g. Minami, Kurushima, Kita), and also in China (e.g. Jiangyin, Xiling, Tiger Gate, assumably also Runyang and Yichang, but not Tsing Ma). Those countries have factories needed for this technique.

The hangers of the Akashi Bridge are vertical. This is the case with all long-span suspension bridges after the completion of the Humber Bridge in 1981. Only 3 major suspension bridges have inclined hangers: Humber, Bosporus, and Severn.



Leena Virola measuring the 1/1-scale model of the main cable of the Akashi Bridge near the Maiko Pavilion on the north shore (Kobe side). (Photo: Juhani Virola)

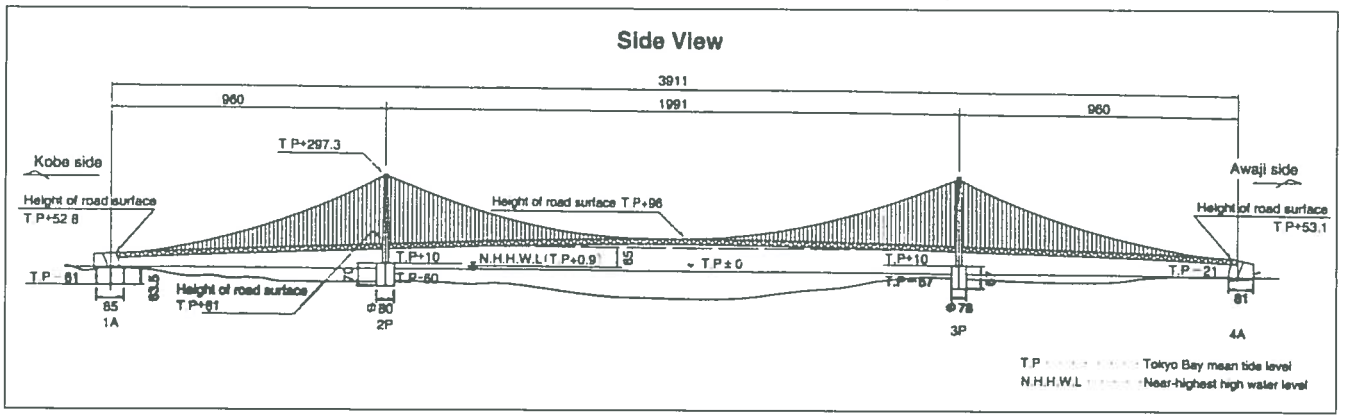
Akashi Bridge: group photo on the hosts and guests. On the left: Kazuyoshi Kasai and Sumitaka Kurino from the HSBA Kobe Office, on the right: visitors Leena and Juhani Virola from Finland. Photo taken near the Maiko Pavilion. (Photo: Honshu-Shikoku Bridge

Akashi Bridge: hosts and guests on route from the south anchorage to the south tower, along the maintenance lane on the wide steel grid platform at the lower level of the deck, used also by maintenance vehicles. (Photo: Juhani Virola)

Akashi Bridge: view towards Honshu in the north (Kobe side). Photo taken at the top of the south tower (Awaji side). The north tower is looming in the background, at a distance of about 2 km. (Photo: Juhani Virola)

Deck and underclearance

The deck of the Akashi Bridge consists of strong steel truss girders, width 35,5 m, depth 14,0 m. A streamlined steel box girder was studied, but in this case its upper main span limit appeared to be 1600 m, which the Akashi Bridge exceeds by nearly 400 m. It should be mentioned that the following long-



Longitudinal profile of the Akashi-Kaikyo Bridge.

span bridges (>1100 m) have steel box girder decks: Great Belt, Runyang, Humber, Jiangyin, Tsing Ma, Höga Kusten.

The effective width of the Akashi Bridge is 30,0 m and the underclearance is 65 m, while the highest underclearance among major suspension bridges (>1100 m) is 70 m of the Ponte 25 de Abril in Lisbon.

The deck of the Akashi Bridge accommodates 3 + 3 lanes for motorway traffic, design speed for vehicles 100 km/h, no lanes for light traffic. The maintenance traffic is using the wide steel grid platform at the lower level of stiffening girder trusses (likewise we walked along that service route from the south anchorage to the south tower).

Depending on loads, the maximum displacements of the deck may vary within the following ranges: vertically 8 m upwards and 5 m downwards, horizontally 27 m each direction. There are expansion joints at anchorages and hinges at towers.

Severe earthquake at Kobe

The Akashi Bridge is designed for winds up to 80 m/s and also for severe earthquakes of 8,5 on the Richter scale.

On 17th January 1995, an earthquake of 7,2 richters occurred in Kobe area and about 6.000 people were killed [5]. The epicentre of the earthquake was located close to the south end of the Akashi Bridge, several kilometres away from Kobe City itself.

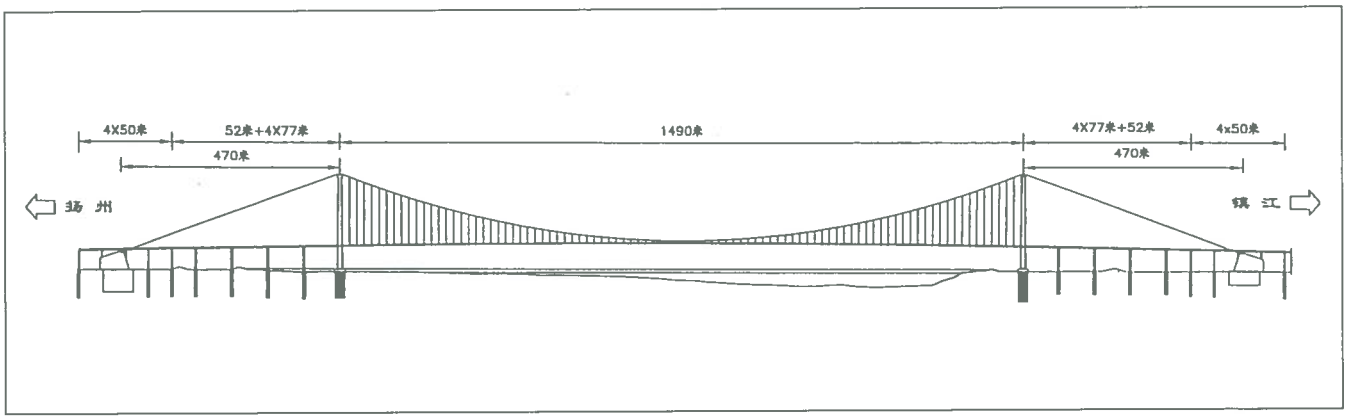
The bridge experienced a severe earthquake resistance test, as the magnitude at the bridge site was nearly 8 richters. When the earthquake occurred, the towers and the cables of the bridge were newly completed, and the construction of the deck was to be commenced. Buildings and bridges collapsed even at a distance of 50 km from the Akashi Bridge. It appeared that the Akashi Bridge survived with only minor damages [11]. Because of the movement of the earth, the south tower moved 80 cm southwards, and the tops of the towers tilted 10 cm southwards.

The main span increased 80 cm and became nearly 1991 m. Also, the south side span increased 30 cm. Accordingly, the total length of the suspension bridge increased 110 cm.

As a result the sag of the main cables decreased by 130 cm. It is estimated that the damages would not have been this slight had the cables not been already installed.

Despite the earthquake, the Akashi Bridge was completed according to the original schedule in Spring 1998.

Artist's impression on the Runyang Bridge when completed in 2005. Suspension bridge on the left, cable-stayed bridge on the right. (Photo: Jiangsu Provincial Yangtze River Highway Bridge Construction Commanding Department)



Longitudinal profile of the Runyang South Bridge.

Organization/Quantity/Cost

The bridge is operated by the Honshu-Shikoku Bridge Authority (HSBA), having its Main Office now in Kobe (earlier in Tokyo).

The Main Consultants are:

- for substructure: Oriental Consultant, Nippon Koei, Yachiyo Engineering, Dainippon Consultant;
- for superstructure: Chodai;
- for others: Sogo Gijyutsu Consultant.

The Main Contractors are, all by JV (Joint Venture), [5]:

- for substructure:
  - anchorage 1A: Obayashi, Shimizu, Tobishima, Toa & Fudo;
  - pier 2P: Kajima, Maeda, Nishimatsu, Goyo & Toda;
  - pier 3P: Taisei, Hazama, Sato, Toyo & Nihon-kokudo;
  - anchorage 4A: Kumagai, Aoki, Fujita & Wakachiku;
- for superstructure:
  - tower 2P: Mitsubishi, Ishihari, Hitachi, Yokogawa & Miyaji;
  - tower 3P: Kawasaki, Sumitomo, NKK, Mitsui & Kawada;
  - cable: Shin-nittetsu & Kobe;
  - deck-1: Miyaji, NKK, Sumitomo, Komai & Nihon-kyoryo;
  - deck-2: Yokogawa, Kawasaki, Tokyo-tekkotsu Mitsui & Topy;
  - deck-3: Mitsubishi, Ishibari, Matsuo, Nihon-sharyo & Kurimoto;
  - deck-4: Kawada, Hitachi, Takigami, Takada & Katayama.

The total cost of the bridge was JPY 500 milliard (500.000.000.000).

Dividing this by the length of the suspension bridge (3911 m) and by its effective width (30,0 m), the area cost is about JPY 4,2 mill./m^2 (4.200.000).

Quantity [5]:

- concrete: 1,44 million m^3 in all;
- steel:
  - for substructure: 68.000 metric tons (t);
  - for superstructure: 193.300 t;
  - steel in all: 261.300 t (2,2 t/m^2).

The costs are amortized by toll payments, and the vehicles are divided into 5 categories. Between Tarumi (in the north) and Awaji (in the south) interchanges, to mention 2 of 5 categories, the cost for an ordinary passenger car is JPY 2600 and for a large special vehicle JPY 7650 one way. These payments apply the 5-year period 1st April 1998 until 31st March 2003, and the toll payments are gathered each direction. Thus, for instance, a round trip to-and-from these 2 interchanges costs JPY 5200 for an ordinary passenger car. During 1998, the daily traffic volume was about 27'000 vehicles on an average.

The greenish-gray colour was selected for the bridge, to harmonize with the sea and sky in the Strait.

The bridge was officially inaugurated on 5th April 1998. Thus it won by a few weeks the 2nd longest-span bridge, the Great Belt East Bridge (1624 m), which in turn was inaugurated on 14th June 1998 in Denmark.

THE RUNYANG BRIDGE, LONGEST-SPAN BRIDGE OF THE NEW MILLENNIUM

In China, a large bridge complex is under construction across the Yangzi River in Jiangsu Province, downstream of Nanjing. Due to the island of Siyezhou in the river, the crossing consists of 2 major bridges which will link Zhenjiang on the south bank of the river and Yangzhou on the north. The south bridge is a suspension bridge with a main span of 1490 m, while the north one is a cable-stayed bridge with a main span of 406 m.

The bridge complex is known as the Runyang Bridge, and its total length is about 23 km, Ref. [12]. The new connection will form an important link in the Beijing-Shanghai Expressway. Construction of the Runyang Bridge was commenced in Oct.2000, due for completion in 5 years by Oct.2005.

With its main span of 1490 m the suspension bridge will rank as 3rd in the world ever built [13]. Only its main span is suspended, the two approach spans are not. The suspension bridge has concrete towers, 215 m in height above water level. The main span consists of a streamlined orthotropic steel box girder, depth 3,0 m. The width of the deck of the main span is 34,3 m between hangers, accommodating 6 traffic lanes, and the overall width is 39,2 m, with a narrow walkway at each outside edge for maintenance access. The under-clearance is about 50 m (measured from drawing).

This brief article on the Runyang Bridge is based on the Ref. [12] and on the material kindly given to the author by the Jiangsu Provincial Yangtze River Highway Bridge Construction Commanding Department, Zhenjiang, China.

Some other long-span suspension bridges are plan-

ned in China, for instance Tsing Lung (span 1418 m) and Lingdingyang (1450 m) [14]; Jiaozhouwan (1652 m or 1800 m) [12]; Qiongzhou (2000 m to 2500 m)[15].

EPILOGUE

Long-span bridges have interested us always, me and my wife, particularly great suspension bridges and also cable-stayed bridges (Tatara). During Oct.1998 we visited the mighty Akashi-Kaikyo Bridge in Japan, Ref. [2], and some other Honshu-Shikoku great bridges, too.

Hitherto, we have visited the following long-span cable-supported bridges (in order of main span): Akashi, Great Belt, Humber, Verrazano, Golden Gate, Höga Kusten, Fatih Sultan Mehmet, Bosporus, George Washington, Kurushima-3, Ponte 25 de Abril, Forth, Severn, Tatara (890 m), Transbay (2 x 704 m).

Excluding the 2 Istanbul suspension bridges, in other cases we were permitted to enter the top of the towers of the bridges mentioned above. The 3 Kojima-Sakaide suspension bridges in the said Table 1 (Minami, Kita, Shimotsui) we crossed only by train at nightfall, so those are not counted.

During our visit to the Akashi-Kaikyo Bridge [2], we were kindly guided by the Kobe Office staff of the Honshu-Shikoku Bridge Authority-HSBA. We were permitted to enter the top of the south (Awaji side) tower by internal elevator at a height of nearly 300 m (297 m). The weather was misty and this had an effect on some of the photos. At the end of the visit to the Akashi Bridge, we were kindly guided to the Tsukuhara Bridge [3], in Honshu, a few kilometres away from the Akashi Bridge.

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