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THE BRIDGE ENGINEERING 2 CONFERENCE AKASHI BRIDGE

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Abstract: The aim of this conference paper is to analyse the Akashi Bridge. This analysis procedure will generally include considerations of aesthetics, loading, strength, serviceability, construction, temperature, creep, wind, durability, susceptibility to intentional damage, and possible future changes which the bridge might have to undergo. All aspects above will be critically examined in the context of how the design and/or construction of the bridge could have been improved.

Keywords: *Akashi-Kaikyo Bridge, Suspension bridge, Laying down caisson method, Truss stiffening girder system, Tuned mass damper, Dry air injection system*

1 General Introduction

1.1 Background of the bridge

The Akashi-Kaikyo Bridge, also known as pearl bridge, is a suspension bridge in Japan that crosses the Akashi Strait, it links Maiko in Kobe and Lwaya on Awaji Island as part of the Honshu-Shikoku Highway.

1.2 The reason to build Akashi-Kaikyo Bridge

Before the Akashi-Kaikyo Bridge was built, ferries carried passengers across the Akashi Strait in Japan. This dangerous waterway often experiences severe storms, and in 1955, two ferries sank in the strait during storm, killing 168 children. The ensuring shock and public outrage convinced the Japanese government to draw up plans for a suspension bridge to cross the strait. The original plan was for a mixed railway-road bridge but when the bridge was begun in April 1986, it was restricted to road only, with six lanes. Actual construction did not begin until May 1988, and the bridge was opened for traffic on April 5, 1998. The Akashi Strait is an international waterway and required a 1500 meters wide shipping lane. Ref [1]

1.3 The spans length of the bridge

The bridge has three spans. The central span is 1991 meters, with the two other sections each 960 meters. The bridge is 3911 meters long overall. The central span was originally only 1909 meters but was stretched by a further meter in the Kobe earthquake on January 17, 19995. The earthquake moved the main towers of the bridge approximately 0.8 meters apart as well as shifting them horizontally and causing one to sink and the other one to rise by a small amount. Fortunately the stiffening girder had yet to be erected. Without the girder in place, the structure was lighter and more flexible to take the movements.

It is the longest suspension bridge in the world to date, as measured by the length of its center span 1991 meters, substantially longer than the second longest suspension bridge, the Danish Great Belt Bridge. Total length is 3911 meters. Ref [2]

2 Designs and Construction

2.1 Main design conditions

There were six main design conditions for the Akashi-Kaikyo Bridge:

1. The width of the straits is about 4 km, and its depth along the proposed bridge route reaches about 110m.
2. The natural conditions are: The water depth at the main pier site is 45m, maximum tidal current of 4.0 m/s and maximum wave height of 9.4m
3. The wind conditions are: basic wind speed for design was 46m/s which was defined as 10 minutes averaged speed at 10m above the water level with the return period of 150 years and with a reference wind speed against flutter of 78 m/s
4. The geological conditions are: The base rock beneath the straits is granite, on which Kobe Formation (alternating layers of sand stone and mud-stone in the Miocene), Akashi formation (semi consolidated sane and

gravel layer in the late Pliocene and the early Pleistocene) and the Alluvium layer are deposited.

5. The design earthquake: the one which occurs off the Pacific coast about 150 km away with the magnitude of 8.5 or the ones which are expected within radius 300 km with the return period of 150 years.

6. The social conditions are: a waterway with 1500m in the width and heavy sea traffic is designated amid the straits, and lands on both shores are highly utilized. The bridge is for 6-lane highway with the design speed of 100 km/h. Ref [3]

2.2 Characteristics on construction

The design of the Akashi-Kaikyo Bridge is strongly influenced with the construction method due to the scale of the structure. The design could not be done without consideration about the construction method and procedures.

2.2.1 Decision on span length

According to the surveying data, the minimum clear span length should be 1500m, which is the width of the waterway, however it is better to keep the main piers off the waterway with some space to spare, even during construction to ensure the safety of maritime traffic, as was required by law. After considering the range of minimum construction cost, the topographical and geological conditions, the designers finally decided to make the main span length of 1990m.

2.2.2 Laying Down Caisson Method for underwater foundation

The two main piers were decided to be direct foundations having circular plane shape, and Laying-down caisson method was selected for their construction. And they use an improved excavation method and underwater concreting method from previous bridge project due to various technical developments done after then. Ref [4]

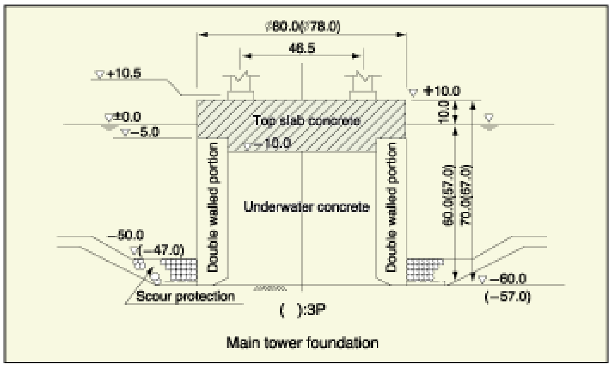


Figure 1: Design of the underwater foundation

On the other hand, the caisson had a possibility to overturn from scouring due to the accelerated flow and horse shoe vortexes both which were generated by presence of the caisson itself unless some countermeasures were taken, because the Akashi straits had sea bottom covered with sand and gravel and its tidal current was rapid. Accordingly, protection against the scouring with filter units and cobble stones laid on them were placed.


Figure 2: Protecting of the caisson against scouring

2.2.3 Foundation and Anchorage

The side span length was determined to be 960m so that both anchorages were located near the original shore lines, so it was easier to obtain the working yard by reclamation. The body of two anchorages was designed to be a conventional gravity type. And many people could make easy access due to the anchorage body is only a huge reinforced concrete structure. Also the shape of anchorages were designed so as to lessen an oppressive feeling, and precast panels were used as remaining form which had superior external appearance and pattern to avoid monotony of the concrete surface. These panels could also raise the durability of the mass concrete cast in-situ.

On the other hand, two foundations were quite different by reflecting difference of the geological condition. Especially, the one on Kobe side was the world's largest foundation for a bridge with a diameter of 85m and the bottom depth of 61m underground. The foundation was constructed safely and surely by using underground slurry wall method. Various kinds of concrete, from the slurry wall to inner concrete of foundation, were used. Precast concrete panels were installed considering the esthetics of the outside walls. High workable concrete was used for anchorage boy. Ref [5]


Figure 3: Construction of anchorage

2.2.4 Newly Developed Building Material

Low heat generating type cement, which contains less clinker and thus decreases hydration heat, were newly developed and widely used. For various parts of the substructure, several kinds of new concrete mix were investigated and used so as to meet required quality such as the strength, the consistency, the maximum size of aggregate, the adiabatic temperature rise and so on. Some examples were desegregation underwater concrete for the main piers, Roller Compacted Concrete with 40 mm aggregate for the foundation on Kobe side, highly workable concrete for the anchorage body. Ref [6]

2.2.5 Main Tower and Shaft

The main tower was made of steel, and the shaft has cruciform cross section which is insensitive to wind induced oscillation. However, Tuned Mass Dampers were installed inside the shafts to suppress the oscillation which was anticipated during the tower erection as well as even in the completed stage of the bridge. Tower shafts were divided into 30 tiers and almost of all tiers were composed of 3 blocks. Each block was precisely fabricated in factories and transported to the site, and then hoisted up for the erection with a self- climbing tower crane which had a lifting capacity of 1.6 MN. High tension bolt joints were used for the field connection. The towers and the suspended structure were coated with newly developed with fluorine-resin paint which had high durability, and in this coating system, zinc-rich paint put directly on the steel surface played as important role to exert the anticorrosion performance. Ref [7]

2.2.6 Main Cable and Hangers

The main cable was made of parallel wires which were erected with Prefabricated Strand Method having been used long in Japan because of its superiority on resistance against wind action and number of required workers during the erection. A cable is composed of 290 strands each which contains 127 wires measured 5.23mm in diameter. High Strength of 1800 N/mm2 galvanized wire was developed and used for the main cables, which could avoid to use double cables per side even when the span of the bridge was very long and sag to span ratio was kept 1:10. This sag to span ratio enabled to restrict the height of the main towers.

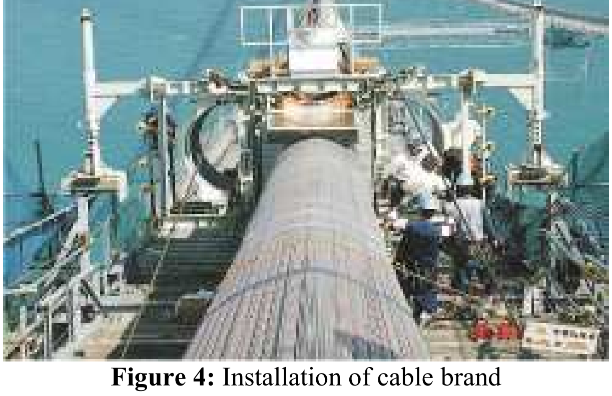


Figure 4: Installation of cable brand

In the cable erection, the 10mm diameter poly-aramid fiber pilot rope was carried across the strait by helicopter, eliminating the storm rope system from the catwalk and so on was utilized. Also, corrosion prevention system for the main cables was developed, in which dehumidified air flowed through void inside the main cable and thus removed the moisture. As for the suspender ropes, parallel wire strands wrapped with polyethylene tubes with pin connection at both ends were newly used to ease future burden of the maintenance work.

The hangers of the Akashi-Kaikyo Bridge were vertical. This is the case with all long span suspension bridges after the completion of the Humber Bridge in 1981. Ref [8]

2.2.7 Truss Stiffening Girder and Deck

The truss stiffened girder was selected because the type was advantageous over stream lined box girder from the viewpoints of securing aerodynamic stability and easiness of the erection to be done on a strait where use of the beneath sea surface had been judged difficult.

For precise evaluation of the aerodynamic stability of such a long span bridge, it was considered necessary to conduct 3-dimensional test with aero-elastic bridge model in addition to the conventional 2-dimentional test with rigid partial model. A boundary layer large wind tunnel in which a 40m long model was accommodated was thus constructed to verify the safety of this bridge against wind action. An outcome of this test was to establish flutter analysis method, which could calculate the critical wind speed of flutter without depending on large sized wind tunnel test.

Figure 5: A 1:100 scale Akashi-Kaikyo Bridge model undergo wind tunnel test.

At the site, the truss members, which were pre-assembled into plane shape panel, were hoisted up to the deck level at the main towers, supplied to the erection front and connected to the existing truss members with a traveler crane. And finally, suspenders were fixed to this newly erected portion. This erection method had been widely used in Japan because it could avoid disturbing the sea traffic beneath the construction and because it was superior in securing aerodynamic stability during erection.

The deck could accommodate 6 lanes for motorway traffic and the design speed for vehicles is 100km/h, no lanes for light traffic. And the maintenance traffic used the wide steel grid platform at the lower level of stiffening girder trusses. And the deck was designed to be flexible that had an allowance of 8m upwards displacement, 5m downwards displacement and 27m horizontal displacement in each direction. Ref [9]

3 Loading

In the process of analysis of the bridge, I have made assumption that the worst case is the span in the middle, which has a span length of 15m between two cable hangers. And it is simply supported by two cables.

3.1 The ultimate limit state

The overall dead load of the bridge is 140 KN/m
The superimposed load of the bridge is 20 KN/m
The Traffic Live Load:
The carriageway of the bridge is 35.5m which is equal to 6 notional lanes. And the corresponding nominal HA udl is 30KN/m, KEL per notional lane is 120KN and HB KN per axis loading is equal to 250 KN for a 9.8m long truck.

For the wind load, I first calculate the maximum wind gust Vc by

$$Vc = V \cdot K_1 \cdot S_1 \cdot S_2 \quad (1)$$

Where V is the mean hourly wind speed, K_1 is a wind coefficient, S_1 is a funneling factor generally taken as 1.00 and S_2 is the gust factor.

Table 1: Maximum wind gust Vc

V	K_1	S_1	S_2	Vc
37 m/s	1.5	1.0	1.36	75.48 m/s

The horizontal wind load can be calculated by equation

$$Pt = q \cdot A_1 \cdot C_D \quad (2)$$

Where q=0.613 Vc^2, A_1 is the solid horizontal projected area in m^2 and C_D is the drag coefficient.

Table 2: Horizontal wind load Pt

q	A_1	C_D	*Pt*
3492 N/m²	13937 m²	1.3	31.78 KN/m

And the uplift force by wind are calculated by equation

$$Pv = q \cdot A_3 \cdot C_L \quad (3)$$

Where q is the dynamic pressure head A_3 is the plan area and C_L is lift coefficient.

Table 3: Uplift wind load Pv

q	A_3	C_L	*Pv*
3492 N/m²	70680.5 m²	0.4	49.49 KN/m

After finding the value of γ_{f1} and γ_{f3}, we can then find the factored loadings.

Table 4: Factored Loadings

	γ_{f1}	γ_{f3}	Loading	Factored Loading
Dead Load	1.05	1.10	140 KN/m	161.7 KN/m
Superimposed Dead Load	1.75	1.10	20 KN/m	38.5 KN/m
Traffic Live Load HA	1.10	1.10	70 KN/m	84.7 KN/m
Traffic Live Load HB	1.10	1.10	250 KN	302.5 KN
Traffic Live Load KEL	1.10	1.10	120 KN	145.2 KN
Wind Load Uplift Suction	1.10	1.10	49.59 KN/m	60.0 KN/m
Wind Load Horizontal	1.10	1.10	31.78 KN/m	38.45 KN/m

Because of the uplift wind load would cancel out the other downward loadings, so the worst case should be the first combination of load, which is all permanent loads plus primary live loads. And I work out the maximum bending moment at the mid span is equal to 11060.34 KNm.

By using the following equation, I can work out the depth of the deck which can take the calculated moment above.

$$M = \sigma \cdot I / y \quad (4)$$

σ	I	y	M
275 N/mm²	23.67 m4	3.5m	1859785.71 KNm

Where M is the bending moment, σ is the design strength of material, I the second moment of area and y is the distance between point and nature axis.

In conclusion the calculated M is far too much bigger than the one the bridge need. There may be some thing wrong in my assumption, such as the estimated value of I for the girder section and the position of the natural axis.

And then I work out the stress induced by the change of temperature by using the following equation

$$\sigma = \Delta T \cdot \alpha \cdot E \quad (5)$$

ΔT	α	E	σ
20℃	12x 10₆/℃	200000	48 N/mm²

Where σ is the stress induced, ΔT is the change of temperature, α is the coefficient of thermal expansion and E is the Young Modulus of steel.

The axial stress induced by change of temperature is 48n/mm². And in fact, the design of the bridge tower is flexible to take than thermal expansion and it allow an expansion of 1.45m with the present of the expansion joint. So this should not be a problem in term of this.

4 Aesthetics

Because the bridge was to be located within easy access of many people, aesthetic design with the following themes was developed.

Figure 6: Akashi-Kaikyo Bridge

4.1 Function

The Akashi-Kaikyo Bridge expresses its structure in a pure and clear form. Every element of the bridge were showed clearly such as the supporting tower, the deck, the stiffening truss, etc. From its appearance, you can easily identify the function of each part of the bridge. Although it had the world longest suspending span, the truss structure would still give people a feeling of stability. It has an impression that the bridge can withstand every kind of load caused by typhoon, earthquake or heavy traffic And suspension bridge was the best suitable bridge type for this wide strait by having only two main supporting tower without disturb the marine traffic.

4.2 Proportions

The Akashi-Kaikyo Bridge had an excellent proportion between the height, length and spans. The proportion between them was just right for a bridge.

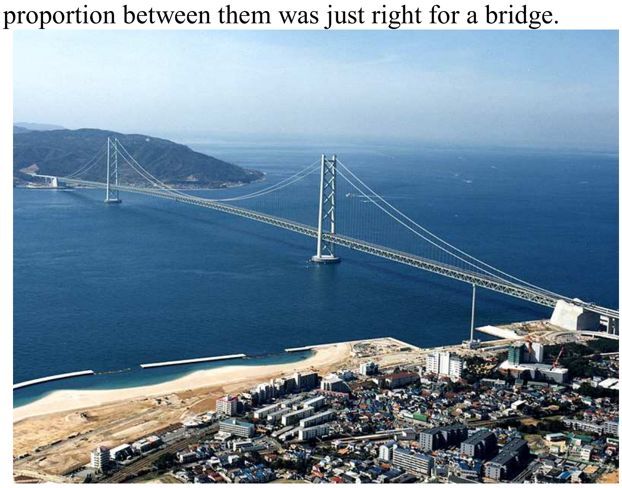


Figure 7: Akashi-Kaikyo Bridge showing its proportion

4.3 Order

The Akashi-Kaikyo Bridge had a very good order. The amount of lines and edges were just enough. And all straight line appeared on the bridge are very clear, showing a very good order in the bridge.

4.4 Refinement

The Akashi-Kaikyo Bridge shows a very good combination between light and shadow that it expresses essence of beauty of the Seto-Inland Sea, harmony and relentless change of the light and the shadow.

Figure 8: Akashi-Kaikyo Bridge showing its order

4.5 Integration into the environment

The Akashi-Kaikyo Bridge looks absolutely beautiful across a wide span of water as a suspension bridge Its simple combination of tower and cable gives people a feeling of claim, as claim as the gentle sea water.

4.6 Surface texture

In the design of Akashi-Kaikyo Bridge, the engineers use several different types of concrete to construct the anchorages, foundation and the deck. Therefore there will be different appearance for different parts of the bridge.

Figure 9: Akashi-Kaikyo Bridge

4.7 Colour

The designer chose the colour of green-gray for the bridge. It was because the colour matched the design themes and evoked forest-rich Japan. In addition, the bridge illumination was arranged, in which the colour of cable illumination can be changed monthly or seasonally following pre-determined plan.

Figure 10: Akashi-Kaikyo Bridge showing it colour and character

4.8 Character

The Akashi-Kaikyo Bridge has a strong character on it's the world's longest span. Many people would wonder how the bridge to suspend such a long span. Of course the reasons behind is having the biggest foundation ever beneath the supporting tower for bridge.

5 Serviceability

The Akashi-Kaikyo Bridge was designed on a two-hinged stiffening girder system which allows the bridge to withstand 286 kilometers per hour (178 mph) winds, earthquakes measuring up to 8.5 on the Richter Scale, and harsh sea currents. The bridge also contains pendulums that operate at the resonant frequency of the bridge to dampen forces on it. The two main supporting tower are 298 meters above sea level.

5.1 Wind loading

The increase in span length of long span bridges results in remarkable decrease in their natural frequencies and the ration between the fundamental torsional and vertical mode frequencies. So the long span bridges are very susceptible to the actions of strong wind.

Akashi-Kaikyo Bridge has the world longest span of 1991m. This indicates the significance of aerodynamic design in long span construction. This long span bridge may experience vortex-induced vibration, turbulence-induced buffeting and motion-induced flutter instability.

During the analysis process, the Public Works Research Institute (PWRI) constructed a 1:100 scale model and tested it in a large wind tunnel to investigate the aerodynamic behavior of the bridge.

5.1.1 Three-dimensional analysis of coupled flutter

In order to analysis the coupled flutter of the bridge, they use the Miyata and Yamada's 3D FEM model to combine all the structural and aerodynamic properties and variables and then bring it to complex eigenvalue analysis. This model succeeded in explaining aerodynamic damping or exciting behavior of the complicated coupled flutter instability as shown in fig.1.

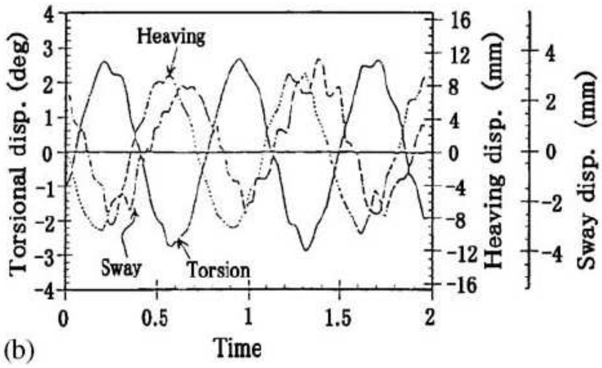


Figure 11: Characteristics of the wing section 3D flutter onset in full-scale model of the Akashi-Kaikyo Bridge time history response at mid-point of center span (8.4 m/s)

This figure shows a response record during coupled vibration of three degrees under large lateral deflection and windward-down rotation at the center by wind loading.

The model is effective to describe the measured aerodynamic behavior of damping or exciting motions, which was very close to the calculated results as shown in fig.2.

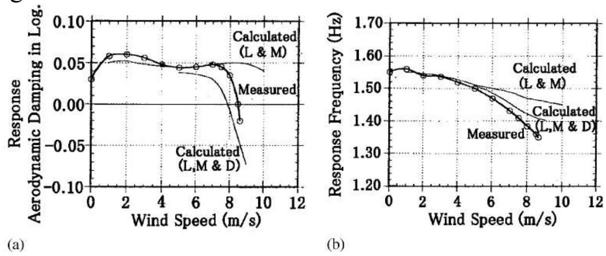


Figure 12: Change of aerodynamic response of 1:100 full-scaled aero elastic model of the Akashi-Kaikyo Bridge with wind tunnel speed, (a) response aerodynamic damping in logarithmic decrement, (b) response frequency in torsional, branch.

In reality, there was a report saying that the Akashi-Kaikyo Bridge has no abnormal behavior under the typhoon conditions. Typhoon No.10 went ashore in Shikoku and Kinki area on August 8th and 9th in 2003, and passed along the Akashi-Kaikyo Bridge. According to the bridge motion observation equipment installed, maximum mean wind speed per ten minutes was 26.2 meters per second, and instantaneous maximum wind speed was 34.7 meters per second. According to GPS data set up at the midpoint of the center span, maximum horizontal displacement was 154cm and wind velocity in transverse direction at that time was 17.2 meters per second. Ref [10]

5.2 Earthquake

Since the nearest seismic fault was just 90 miles away from the bridge site. So the engineers had to take some necessary precautions, designing the bridge to withstand an earthquake that would measure 8.5 on the Richter scale.

5.2.1Considerations

After considering the size of the foundations and relatively soft supporting ground, they developed a new seismic design method and apply it on the bridge design, in which concepts of 'the effective seismic motion' and 'dynamic damping effect by interaction between foundation and ground' were introduced.

Also the engineers calculated the two most critical types of earthquakes as factors in designing the bridge. The first one was an earthquake of magnitude 8.5 on the Richter scale with an epicenter distance of 150Km, and the other one was occurring with a recurrent cycle of 150 years within a 300Km of radius of the bridge site. Results from these tests were then applied into the design standards of the bridge. Ref [11]

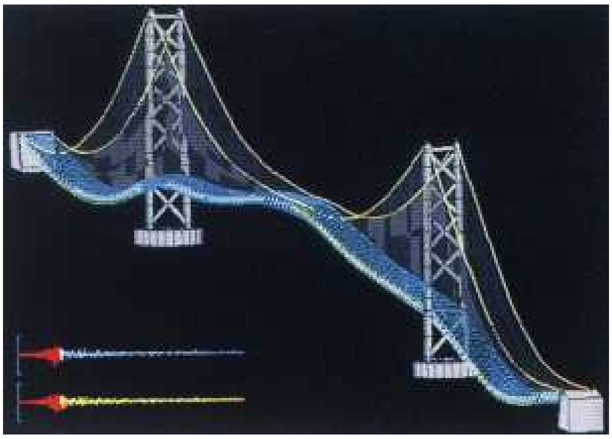


Figure 13: Akashi-Kaikyo Bridge model under seismic vibration

5.2.2 Tuned Mass Damper

Under these considerations, they installed a tuned mass damper, which was tuned to specifically counter harmful frequencies of oscillation, to resist the vibration by both strong wind and earthquake. These vibrations would cause the main support towers to sway and would lead to failure. So inside the system, there is a 10 ton pendulum damper which would swing in the opposite direction of the main support towers movements to keep them stable. Ref [12]

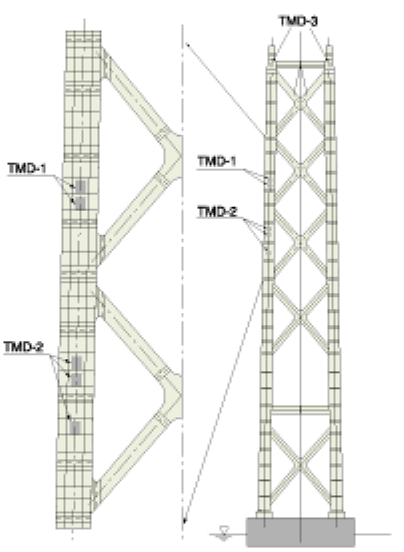


Figure 14: Location of Tuned Mass Damper

5.2.3 Temporary Active Mass Damper for erection of min tower

They also use the temporary active tuned mass damper in the erection of main towers of the bridge. The application to free standing main tower of about 300m high Akashi-Kaikyo Bridge was really effective in reducing a variety of wind-induced vibrations which were estimated in the wind tunnel studies in advance. These devices also worked as a sort of an exciter to carry out the field observations later. As for the main tower of this bridge, the system gave passive type of damping systems were to be installed inside the tower sections and between the stiffening girder and the towers.

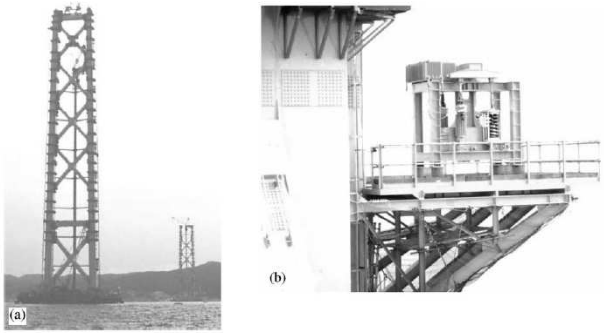


Figure 15: Installation of vibration control devices in the Akashi-Kaikyo Bridge, (a) free standing tower of 300m high, (b) a set of active damper system applied to erection stage only.

The damping system was first accidentally tested by Kobe earthquake on January 17, 19995 during its construction. And fortunately these seismic designs were succeed to withstand the seismic vibration earthquake in 1995 without receiving any structural damage. Ref [13]

6 Temperature

Most parts of the Akashi-Kaikyo Bridge were made of steel. And steel would undergo thermal expansion and contraction. This caused both the deck and the tower had a significant expansion in their length. And this would result in introducing a large amount of moments and shear forces on the piers.

And the design of the pier was to be flexible facing this problem. The pier would allow the movement to occur in order to reduce the induced moment and share forces to the least.

Moreover, these expansions would cause the tower to incline. So the inspectors would carry out the measurement of the degree of inclination of the tower only at night when the temperature is relatively stable.

Measurement was performed by geometer attached the block mirror in tower. And the result was understood that high accuracy of 29mm was attainted as an inclination of the main tower. And with the presence of the expansion joint, the stiffening girder had a horizontally allowance of 1.45m. Ref [14]

7 Improvement

7.1 For Substructures

7.1.1 Prolonging the life of concrete structures

The environmental conditions for the concrete structures of Akashi-Kaikyo Bridge were so severe that they have to maintain with the utmost care and cost. Moreover, it is very difficult to approach the parts of them because of the height to pass marine traffic. Therefore, they could conduct high investigation of accuracy instead of usual maintenance and select the suitable maintain method for these concrete structures. Also the could employ pre-cast concrete panels or paint coating on surface concrete in order to prolong the life and to keep the beauty. Ref [15]

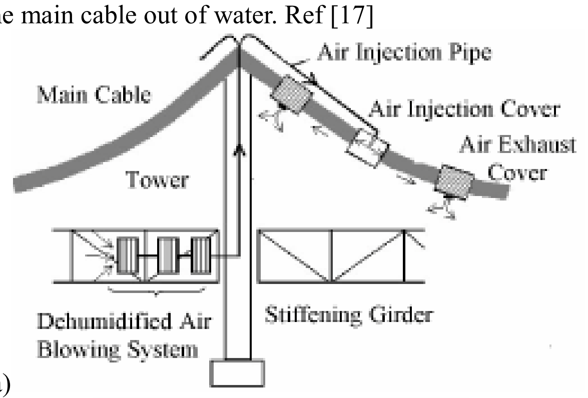
7.1.2 Maintenance for underwater steel structures

The engineers used the Laying-Down Caisson Method to construct the underwater foundations of the bridge. By inspection, they found that there were hole corrosion on the body of caissons. To solve this problem, they could use Electro Deposit Method, which is one of the countermeasures for corrosion of underwater structures and covers surface of structure with the deposit bonded by slight electric current, in order to protect the steel from hole corrosions. [16]

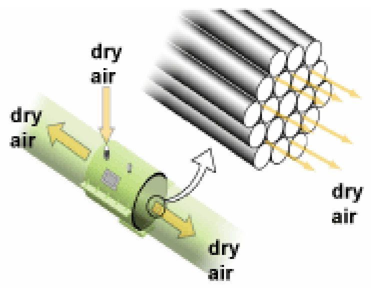
7.2 For Cable

7.2.1 Dry Air Injection System for main cables

The conventional anti-corrosion method for the main cable is such a system composed of zine galvanization of steel wires, and obstruction of seepage of rain water into the cables with paste applied to the cables and with wrapping as well as painting. However, survey on the bridge revealed that prevention of seepage of water was insufficient. In order to solve this problem, they installed the dry air injection system to keep the interior surface of the main cable out of water. Ref [17]



(a)



(b)

Figure 16: Dry Air Injection System for the main cable

7.2.2 The non-destructive inspection for suspender rope

A newly developed non0estructive inspection technique that used an electromagnetic method to identify the degree of internal corrosion of the suspender ropes by comparing the amount of flux between the intact cross section and corroded cross section. This could help to reduce the life cycle cost of the ropes because they could realize the appropriate repair time and select the adequate repair method by the calculation based on the data acquired by this method. Ref [18]

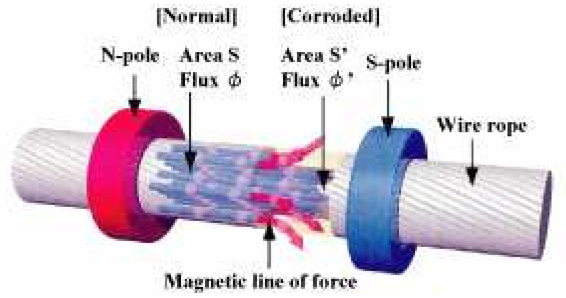


Figure 17: Principle of Main Flux Method

7.2.3 Damping of wind inducted oscillation

The suspender cable of Akashi-Kaikyo Bridge is Parallel-Wires Strand wire covered by Poly-Ethylene tube and two suspender cables at one point.

Originally, a connecting type damper with high damping rubber was installed amid pair of the hangers in order to suppress vortex-induced vibration, which had limited amplitude and was generated at relatively low wind speed, but the damper was eventually destroyed from large amplitude oscillation by high wind speed. The reason of this phenomenon is considered to be wake induced flutter, which had not been anticipated to occur at this center spacing. Wind tunnel test was conducted to investigate the reason, occurring conditions and mechanism of such oscillation. After that, the engineers used a twisting thin wires surround the cables to reduce the oscillation in order to improve the aerodynamic characteristic of cable. Ref [19]

7.4 For Super structure

7.4.12 Magnetic wheel gondola

Conventionally, gondolas were used for the repainting of the main tower of bridge, however, the gondolas would shake in the wind, thus the efficiency of the work decreases and it becomes danger. They could use magnetic wheel gondola with strong magnets in order to stick in on the tower wall. Also there were an object for tower wall and an object for diagonal and horizontal member in the gondola, so it could approach all over the tower member. This would improve the efficiency and degree of safety. Ref [20]

Figure 18: Magnetic wheel gondola work on (a) tower wall and (b) diagonal and horizontal member.

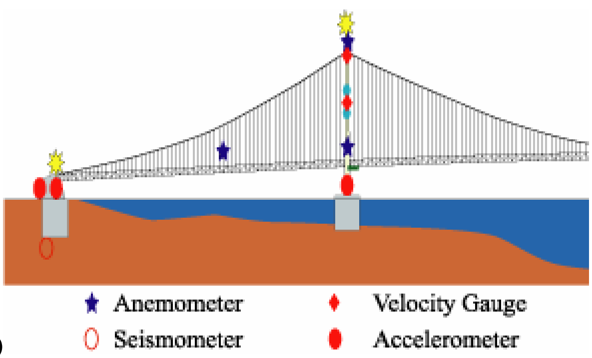
7.4.2 Painting Robot for Girder

The painting robot had a rotating brush, roller painting, supporting joint arms and traveler in order to make an effective repainting for the girder. The robot is set on the moveable maintenance platform. We can repaint whole area of box girder by longitudinal moving of robot and transverse moving of platform itself. By this robot, they could automatically repaint more than 500m2 per day and improve the painting quality, cost saving and working safety. Ref [21]

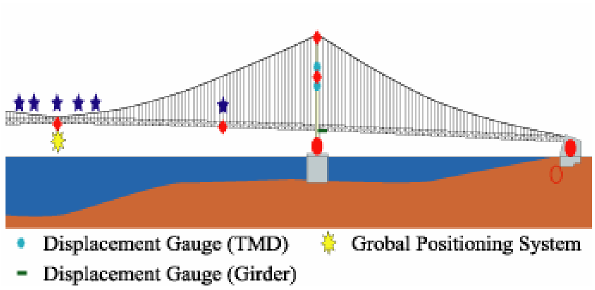
Figure 19: (a) Moveable maintenance platform (b) Painting robot

7.4.3 Bridge monitoring System

To inspect the bridge, there were few various monitoring devices such as seismography, anemometer, accelerometers have been installed and their data were ro be recorded. The record will be accumulated and analyzed to ensure the structural safety by monitoring behavior of the bridge. They can also be used as a precious information about characteristic of long span bridge and nature such as coherence and scale of the eddy of the gusty wind and on. In addition to the system, GPS is introduced to monitor seasonal, daily and hourly behavior the bridge, which will be governed mainly by temperature and the live load. Ref [22]



(a)



(b)

Figure 20: Location of monitoring system for Akashi-Kaikyo Bridge (a) left of the Bridge (b) right of the bridge

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