Cable Stayed Structures and Stay Cable Technology

Case Studies from Europe, Asia, Australia and the Proposed First New Zealand Project

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INTRODUCTION

Cable Stayed Bridges have been built in rapidly increasing numbers since 1950 and have been found to be especially economical for medium to long-span bridges from 100 to 1000 meters, where technical and economic considerations dictate a cable stay solution. Nevertheless, their popularity and wide usage is, according to Menn [1], often based on prestige rather than structural efficiency or economy.

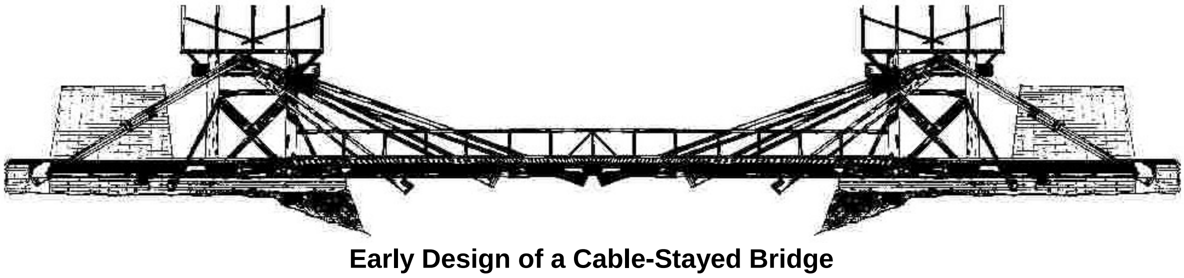
This paper provides a brief historical review of cable stayed bridges, cable technology and sample projects limited to projects in Europe and the Asia-Pacific region with a key focus on Australia and New Zealand are discussed in this paper. In addition, reference to further specialist reading on the various relevant topics is made.

HISTORY OF CABLE-STAYED BRIDGES

The idea to support a bridge deck with cables from one or two pylons has been known for a long time. To the author's knowledge, the principle of cable-stayed bridges can be tracked back to the early 1600's when the Venetian Verantius built a wooden bridge supported with chain stays. In 1784 the carpenter C. J. Löscher designed a cable-stayed bridge with an approximate 32 m span length where the entire bridge was made out of wood, including the stays.

In the 19th century, the French engineer Navier studied several bridge systems supported by wrought iron chains. The results of his studies show that suspension bridges should in general be preferred over cable-stayed systems. From today's point of view, it can be said with certainty that Navier's final conclusions were wrong. However, at the time Navier was studying these different bridge systems, the knowledge and equipment to achieve an even distribution of the load between all the cables, which is one of the key issues for cable-stayed bridges, were not available.

German engineers pioneered the design of cable-stayed bridges after World War II. The German engineers were challenged to find new, innovative, and inexpensive bridge designs to replace most of the Rhine river crossings which were destroyed during World War II. Dischinger proposed systems, where the central span was supported by a suspension system and stay cables carried the outer parts. Dischinger's combined solutions were never adopted for an actual bridge, but his studies had a big influence on the development of the true cable-stayed bridge system. It was not until the 1950's that Dischinger designed the first true cable-stayed bridge. The Strömsund Bridge (Sweden, 1955) had a main span of 183 m and two side spans of 74.7 m. Gimsing [2] attributes the increase in cable-stayed bridge designs to the improved structural analysis tools that were available. The Germans further developed the design of cable-stayed bridges in the following decades and built several of them. The series of bridges near Duisburg across the Rhine River are examples of these pioneering German bridges.



Early Design of a Cable-Stayed Bridge
Europe (1784)

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STAY CABLE TECHNOLOGY

Durable and efficient long span cable stayed bridges require efficient, high strength and high amplitude fatigue resistant stay cable technology. In the past many cable systems have been used, such as locked-coil, wire ropes and bars. Nowadays, these technologies do not meet the demands anymore and modern stay cables consist of wires or strands. Locked-coil cables still find their field of applications in architectural structures with reduced structural requirements. Technical information on modern and state of the art wire and strand stay cable technology can be found in [2, 3, 4].

Wire Stay Cables

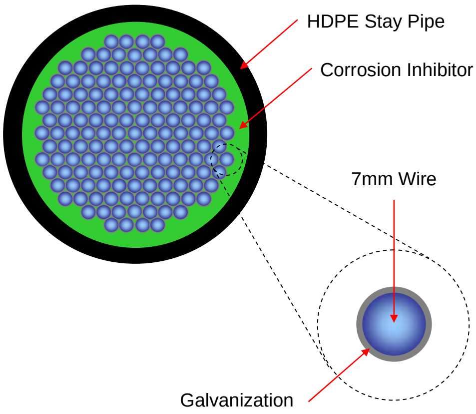
The first stay cable technology available that provided the required static strength and high amplitude fatigue resistance were parallel wire cables consisting of a number of 7mm wires [3]. The anchorage system generally consists of button heads on the individual wires, which transfer the load into an anchor head and into the supporting bearing plate. The usage of full or partial bond type socket anchorages, in combination with button heads on the individual wires, is a further development and is widely used. The first application of high amplitude fatigue resistant wire cables was in the late 1950's in Germany [5, 6]. Today, wire stay cables are made up of a predetermined number of parallel or semi-parallel wires enclosed in an ultraviolet (UV) resistant high-density polyethylene (HDPE) stay pipe or sleeve of circular cross-section. The individual wires generally have a diameter of 7 mm, are individually galvanized and are of low relaxation grade steel, with nominal cross-sectional area of 38 mm^2 and a minimum guaranteed ultimate tensile stress (GUTS) of 1670 N/mm^2 or 1770 N/mm^2. The voids between the individual wires and the HDPE sheathing are filled with a corrosion inhibitor. The anchorages used are in most cases still based on the invention of the button head back in the 1950's.

Strand Stay Cables

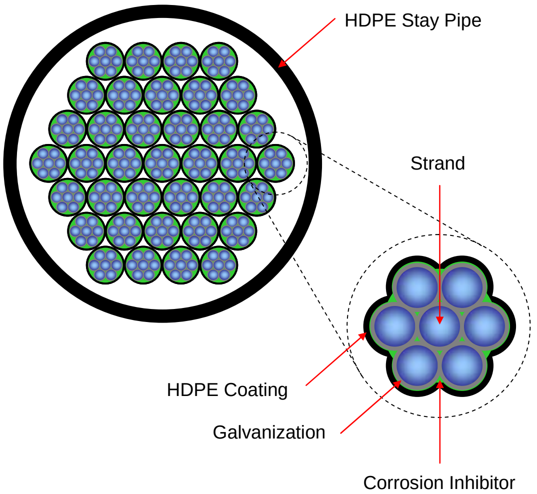
High amplitude fatigue resistant strand stays found their first major application in the Olympic Stadium in Munich (Germany) with its cable supported membrane roof structure. Munich hosted the Games in 1972 and the stadium was home of Bayern Munich, one of the world's premier soccer clubs.

Olympic Stadium Munich
Germany (1972)

Strand stay cable configurations are traditionally anchored by means of the wedges, which bite into the strand and transfer the load into an anchor head and the supporting bearing plate. Epoxy and bond type anchorages have also been used in the past. Modern strand stay cables are generally made up of a predetermined number of parallel arranged strands enclosed in an UV resistant HDPE stay pipe of circular cross-section. The individual strands have generally a diameter of 0.62'' and are of low relaxation grade, with nominal cross-sectional area of 150 mm^2 and minimum GUTS of 1770 N/mm^2 to 1860 N/mm^2. The strands are galvanized, greased or waxed and individually sheathed with a continuous and wear resistant HDPE coating, providing each strand with a triple protection system.



Wire Stay Cable



Strand Stay Cable

Comparison

Both wire and strand type cable systems are today's solutions of choice for modern cable stayed structures. Over the years, the ultimate tensile strength of the wires or strands in the cables has gradually been increased and the corrosion protection systems have been enhanced. Whereas grout was a widely used corrosion protection system for many years, today's stay cables employ grease and wax as the primary filler. Although poor or faulty grouting can result in poor performance of the cables, there are many examples of grouted stay cables which have been inspected and found to be in perfect condition.

Due to the fact that wire stay cables are generally prefabricated and strand stay cables are more commonly assembled on site using a strand by strand installation method, the choice of the suitable cable system for a particular project depends on many factors.

Wire Stay Cables

- A prefabricated wire stay cable is fabricated to a pre-determined length with certain length adjustability at the anchorages and requires transportation and heavy lifting equipment on site. The prefabrication results in a very short erection time on site.
- The cable diameter for wire tendons is more compact which has a series of very significant aerodynamic advantages.
- The Fatigue resistance of wire stay cables is generally higher compared to strand cables.

Strand Stay Cables

- A site assembled strand stay cable is more labor intensive on site, but requires only limited capacity lifting equipment is required.
- For the installation on site, a larger HDPE stay pipe diameter is required, which can have a negative influence on aerodynamic issues.

It has been often considered that prefabricated wire cables are best suited to smaller bridges or those with very long spans. On site fabricated strand stay cables are usually suited to intermediate range spans. However, the designer together with the specialist stay cable company should evaluate each project individually, taking structural capacity and the global interaction between cables and the structure into account. It should also consider erection requirements as well as the overall economics and availability of the various systems.

Cable Vibration

Despite the wide use of cable-stayed bridges, there are still several areas of great concern, especially the effects and elimination of cable vibration phenomena. Even newly constructed cable stayed bridges have experienced quite severe vibrations which may result in failures of cables [7].

Several cable vibration mechanisms have been identified and characterized with the four most common phenomena: vortex shedding, galloping, parametric excitation (deck/pylon and cable interaction), and wind and rain induced vibrations. Excitation mechanisms and preventative design measures are a popular topic in the literature [8, 9, 10, 11, 12, 13, 14].

An effective countermeasure against wind and rain induced vibrations is the use of a helical rib on the outside of the cable surface. The helical fillet helps to prevent the formation of the coherent water rivulets, which are responsible for the cable vibrations and therefore mitigates the excitation at its source. Other cable surface treatments include dimples (such as used for golf balls) and longitudinal grooves. If the natural frequencies of the structure are close to those of the cable stays, cross-ties (wind ropes) can be installed to shift the natural frequencies of the cable stays and to avoid a possible interaction of deck and pylon with the stay cables. Supplemental damping devices add damping to the cable – hence achieving sufficient total damping as an efficient measure against cable vibrations. If the cable begins to vibrate, with the movement of the cable at the position where the cable is attached to the damping device, energy is dissipated through the damper to stabilize the cable. Typical supplemental damping devices for cables are high damping "rubber doughnuts", mechanical / friction dampers and hydraulic dampers.

Future Developments

To enhance the long term durability of the stay cables, the use of epoxy coated strands as well as the injection of the stay pipe with gas to prevent corrosion are more recent developments and potential alternatives for the future.

Storchenbridge
Switzerland (1996)

Furthermore, the Storchenbridge in Wintherthur (Switzerland), crossing the major east-to-west axis of the Swiss Federal Railway Network, was the world's first bridge using carbon stay cable technology. Due to its low self-weight, carbon stay cables are a promising solution for ultra long span bridges. Their extremely high fatigue resistance and the fact that carbon is non-corrosive are further advantages of this type of cable. It should be noted that special care should be taken when choosing an anchorage system for carbon stay cables [6].

SELECTED REFERENCE PROJECTS

Europe

As noted previously, the mother continent of cable stayed bridges and structures is Europe, with the first major applications constructed in the late 1950's. Since the early days of cable stayed bridge construction in Europe, cable stays have been widely used - not only for technical and economical reasons but also for purely architectural considerations.

The scenic ***Sunniberg Bridge*** in the skiing resort of Klosters in the Alps of Switzerland was designed by the legendary Swiss Engineer Christian Menn and was opened to traffic in 2005 by Prince Charles. This masterpiece of engineering, which fuses perfectly with the scenic surroundings, employees a button head type wire stay cable system. Characterized by its short pylons and shallow angle stays, it exhibits the essence of a technical and aesthetic solution in a prominent landmark.

Sunniberg Bridge
Switzerland (2005)

The cable stayed bridge with the longest main span constructed in Europe is the ***Pont de Normandie*** which was completed in 1995. With a main span of approximately 850 m and a pylon height of 215 m the Pont de Normandie was for a short while the longest cable stayed bridge in the world, before its main span was surpassed by 40 m by the Tatara Bridge in Japan. Wedge anchored parallel strand stay cables have been used to realize this bridge.

Asia

Cable stayed bridges are extremely popular in many Asian countries to help resolve traffic congestion and to improve the infrastructure of the incredibly fast growing metropolitans. Japan is probably the country with the highest density of cable stayed bridges. Among the booming countries nowadays is China where a series of future world record span bridges are currently under construction. Cable supported structures in Asia have also been identified as purely architectural and landmark structures and often built to commemorate former or present kings and rulers.

RAMA VIII Bridge
Thailand (2002)

An example of such a structure, which serves the infrastructure, is architecturally appealing and also bares the name of a former King, is the ***RAMA VIII Bridge*** in Thailand. Wedge anchored strand stay cables have been utilized in this bridge which is one of many large bridges which span the river in Bangkok.

Tatara Bridge
Japan (1998)

The longest cable stayed bridge built in the 20th century, the ***Tatara Bridge*** in Japan, has a breathtaking total length of 1480 m, a pylon height of almost 240 meters and employs high amplitude parallel wire stay cables [15].

Australia

The first major application of stay cables in Australia was the unique supporting net structure composed of parallel wire stay cables for the stabilization of the ***Centre Point Tower*** in Sydney, which has a height of 230 meters and which was constructed in the 1970's. Until today, the Centre Point Tower stands together with the Sydney Opera House and the legendary Sydney Harbour Bridge - other famous landmarks found in the city center.

Centre Point Tower
Australia (1978)

Environmental campaigners often claim that the construction of new roads and bridges leads to higher traffic volumes - that they effectively generate additional traffic by providing greater road capacity. In Brisbane (Australia) a new bridge is currently under construction, with the attempt to avoid this criticism by banning private vehicles altogether, and being entirely dedicated to public transport, cyclists and pedestrians. The aptly named ***Green Bridge*** will be Australia's second-longest cable stayed bridge, after the ANZAC Bridge Sydney with a total length of 800m, and will provide bus, pedestrian and bicycle access via its two bus lanes, dedicated cycle way and footway.

The bridge deck is 20m wide, 520m long, and the structure has two 70m-high H-shaped towers. The 64 cable stays are in a harp configuration, arranged in pairs both sides of the two river piers, at an elevation of about 24° to the horizontal. The structural portion of the towers is reinforced, cast in situ concrete, topped with architectural precast. The composite deck consists of steel grillages with precast reinforced concrete planks and in situ stitch joints, in situ concrete barriers to protect the stays against vehicle impact and architectural features on the cycle way and footway. The bus lanes will have a bitumen overlay and the entire bridge is designed to accommodate the possible addition of light rail in the future, including an additional concrete overlay to accommodate the rails.

The bridge is being built using the balanced cantilever technique from both river towers simultaneously. At both towers, the deck grillages are erected alternately on each side of the tower, with cable stays reeved and stressed progressively to provide the appropriate support to the deck during construction and permanently. When the deck steel grillage is in place, the initial stay installation takes place, and the stay is stressed to the minimal load to support the grillage. Next stage is the installation of the precast and stitch concrete; once this has reached the required strength, the second stage stressing is carried out, to achieve the required deck levels. After installation of barriers, deck bitumen and other finishing works, the third stage stressing takes place, to achieve required, final deck levels. The design of the cable stay system includes the provision for future stressing to accommodate light rail.

The state of the art cable technology on the bridge consists of cables with 31 or 37 parallel seven-wire strands enclosed in a UV-resistant HDPE stay pipe in a dark grey color. The strands are galvanized, waxed and individually sheathed with a continuous and wear-resistant coating, providing each strand with a triple protection system. In the anchorage zone, the strand bundle passes though a deviator and spreads out towards the high fatigue resistant anchorages, where each strand is individually guided and locked with high fatigue resistant grips. Ring nuts screwed on to the anchor heads transfer the cable loads by contact pressure to the supporting bearing plates. The individual strands inside the anchorage are protected by a corrosion-inhibiting compound. Finally, the anchor head is covered by a protection cap injected with corrosion-inhibiting compound. With this system, the anchorage is fully encapsulated with a multi-barrier protection system.

Green Bridge
Australia (2006)

The installation of the cable system is performed on site using the strand-by-strand method. Anchorages are first installed in the tower and the deck. The HDPE stay pipe is then hung between the two anchorages using two master strands, and used as a guide for subsequent strand installation. The strand is positioned at deck level and pulled up through the stay pipe to the upper anchorage, using a stay cable strand puller, positioned behind the upper anchorage. Each strand is tensioned immediately after installation, using an iso-stress tensioning method, ensuring an equal force distribution among the strands of an individual cable. Compact multi-strand jacks are used for the final adjustment.

Each individual strand installed in the cable system can be re-stressed at any time during or after the installation, allowing not only for re-stressing but also for the selective removal, inspection, or replacement of individual strands. Deck erection and the final stressing of cable stays is expected to be complete in November 2006, with the bridge and approach works due to open early 2007.

New Zealand
Flat Bush is New Zealand's largest and comprehensively planned new town covering 1700ha for an anticipated population of 40,000 people (the population of Whangarei) by 2020. Located in Manukau, it is close to the new Botany development and west of bustling Manukau City and Auckland International Airport

The scope of the ***Ormiston Road*** cable stayed bridge project can be briefly described as construction of a new landmark bridge, linking Chapel Road with the new Flat Bush Town Centre. The 70m long cable stayed bridge spans over the new Barry Curtis Park. The bridge provides a gateway to the proposed Flat Bush Town Centre, spans a small stream and flood plain and provides a corridor under the bridge that links the two parts of Barry Curtis Park.

The carriageway consists of two lanes in each direction with two footpaths located outside the bridge edge barriers. The carriageway is split by two median barriers and large deck voids. The two pylons anchoring the cable stays are inclined both towards the west and also inwards to the centre of the bridge. A steel portal beam near the top of the pylon provides horizontal restraint. The pylon consists of a tapering concrete section with a fabricated industrial steel box section providing anchorage to the cable stays. The box section is bolted to the top concrete pylon. Architectural tubular cladding covers the box section. A stainless steel lattice tower completes the pylon. The nominated cable system comprises a total of 20 cables utilizing a parallel wire system ranging from 91 to 144 7mm wires inside a HDPE stay pipe injected with a flexible corrosion inhibitor.

Ormiston Road Bridge
New Zealand (anticipated 2007)

The Ormiston Road Bridge will be New Zealand's first modern cable stayed bridge of any significance and it is expected that this pioneering structure for New Zealand will smooth the path for future cable supported structures in New Zealand.

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