Research Task: ANZAC Bridge

Assessment Task 1 – Civil Structures

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Table of Contents

Historical Development

Summary

The ANZAC Bridge, spanning Johnstons Bay, is one of Sydney's most iconic landmarks. It was opened in **December 1995**, at a cost of $170 million and it provides a key link between Sydney City and the suburbs to the west. The bridge is currently the longest cable-stayed span bridge in Australia with a main span of 345m, and a total length of over 800m, however it is far from the longest on a global scale. [1]

In the mid 1980's, The NSW Roads and Traffic Authority (RTA) decides to replace the adjacent old Glebe Island Bridge, an electrically operated low-level steel swing bridge in use since **1903**. [2] Its replacement led to the development of the new Glebe Island Bridge which was given its current name; ANZAC Bridge in **1998 on Remembrance Day**, to honour the memory of the soldiers of the Australian and New Zealand Army Corps (known as Anzacs) who served in World War 1. [3] The ANZAC Bridge was originally planned to have been a conventional concrete box girder construction with support piers in the water. However considering the effects of a large ship hitting one of the piers resulted in the plans to be overruled by the cable stayed option with support towers on the land.

Glebe Island Bridge, 1903

By **1989**, the bridge's construction was well under way with protective embankments and piles being placed to the bedrock and bridge footings for the towers and by **1990** the bridge footings were successfully completed. With rapid progress day to day, there was bound to be a roadblock and this happened in **1991**, where lack of funding led to construction being put to a haul. After one long years' time, in **April 1992**, Federal funding was provided again and construction resumed at an excelling pace.

Eastern Tower, 1994

The ANZAC bridge's structure consisted of two towers, one on the western end and the other on the eastern. The western tower, along with the first three deck segments, were built at the same time and completed by **November 1993** [5], whilst the Eastern tower wasn't completed till **September of 1994**, followed by the Eastern Deck in **June 1995**. The bridge deck was constructed in 10 metre concrete segments and the first three segments were initially supported by scaffolding. However, when tower construction was completed, the first stay cables were installed. They replaced the scaffolding and connected to the deck segment at its furthest edge from the tower.

The construction process of the ANZAC bridge over the water utilised a recent innovation - The Formtraveller - which is, in effect, a travelling formwork. The Formtraveller was supported by the leading edge cables of the previous segment, whilst it provided support for the next 10m concrete segment to be cast. The Formtraveller was itself a substantial construction as it was about 30m long and 32m wide, and weighed almost 280 tonnes. [4]

Formtraveller on the western deck

The joining of the two ends of the bridge took place on **24th July 1995** in the early evening to give the bridge time to cool and time for the final concrete pour to gain strength before morning to avoid movements due to temperature changes. [1] With construction complete it wasn't long before the bridge was open; the opening day walk took place on the **3rd December, 1995**, followed by the bridge being opened to traffic the very next day, **December the 4th**.

Timeline of Historical Development

Mid 1980's: The NSW Roads and Traffic Authority (RTA) decides to replace the adjacent old Glebe Island Bridge.

1989: Bridge footings - steel casings for piles were driven into the bedrock.

Late 1990: Bridge footings were completed.

1991: Construction stopped due to lack of funding.

1992: Federal funding provided again to resume construction.

April 1992: Bridge structure construction commenced.

November 1993: Western Tower constructon completed.

July 1994: Western Deck constructon completed.

September 1994: Eastern Deck constructon completed.

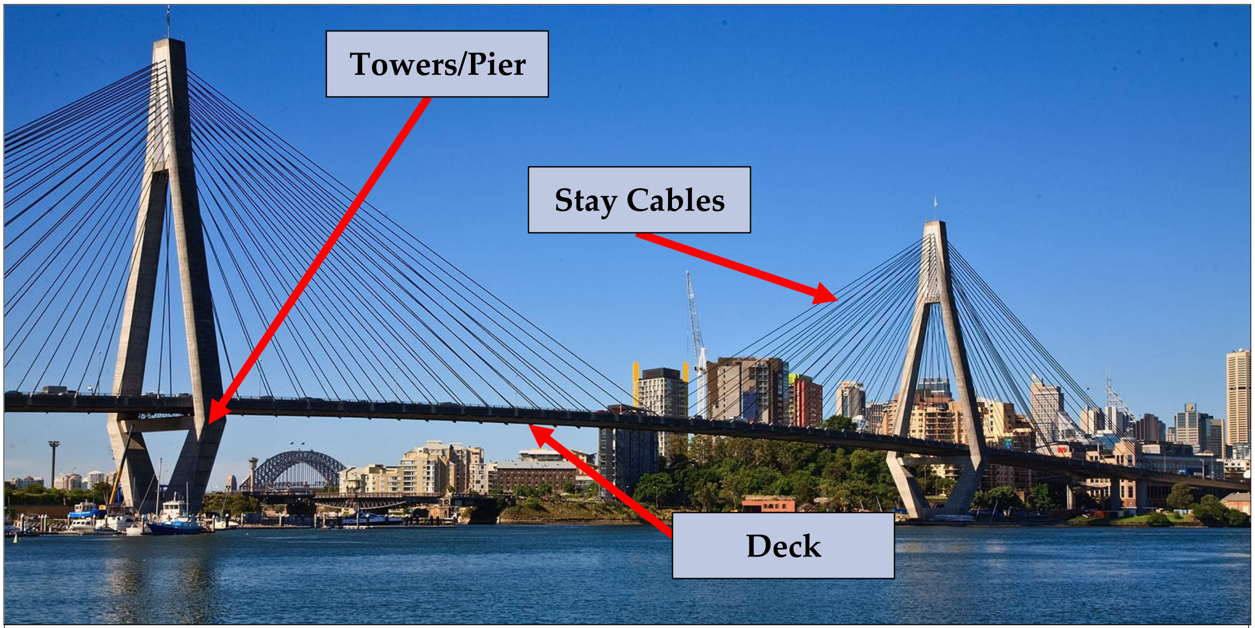
June 1995: Eastern Deck constructon completed.

24th July 1995: Two halves of the bridge joined.

Remembrance Day, 1998: Given its name ANZAC bridge to honour the ANZAC soldiers who have fallen in World War 1.

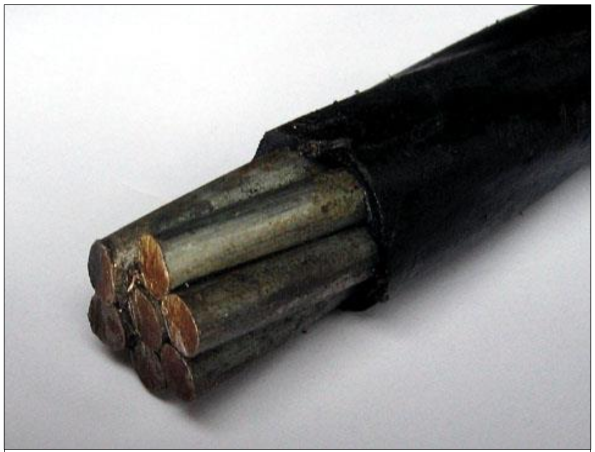
Important Components

Labelled Diagram



Side view of ANZAC Bridge

Stay Cables



Wire strand covered in Polyethylene
[Photographs obtained from site visit]

The stay cables utilised in the ANZAC Bridge's structure were constructed from multiple steel wire strands surrounded by a black polyethylene sheath supplied by Vinidex Pty Ltd. Each individual wire strand was 15.7mm in diameter and consisted upon a minimum of seven galvanised steel wires waxed and covered in polyethylene. Polyethylene is an economical and no maintenance corrosion protection material which was cleverly used in the ANZAC Bridge's construction to prevent **corrosion** and increase **durability**.

Throughout the entire bridges structure the number of strands in each stay cable varied, increasing in number from 25 to 74 towards the centre of the bridge. [5]

12m lengths of polyethylene sheath were welded together on the deck and wire stands were drawn in.

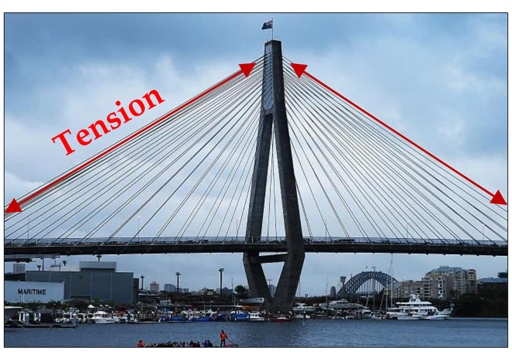
Wire strands within stay cables

The strands were then individually drawn into place through the polyethylene sheath from the deck level using a drawing wheel. They were secured in an adjustable anchorage point in the tower head, the strand was cut to length and fixed at deck level.

Cable strands within the polyethylene sheath and the drawing wheel.

Initially the stay cables were subject to serious vibrations. Experimentation using heavy ropes tying the stay cables diagonally back to the deck solved the problem. The permanent solution replaced the ropes with thin spring loaded stabilising cables between the stay cables and the deck. The spring failure safety link was later added.

Antivibration cable

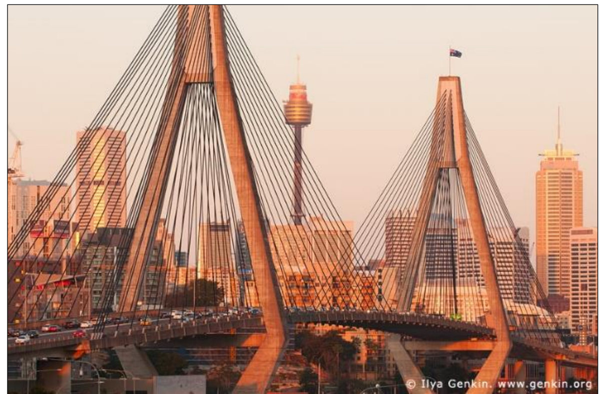


<u>The Stay Cables within the ANZAC Bridge's structure are in **TENSION** just like all cable stayed bridges.</u>

Stress in Stay Cables of the ANZAC Bridge.

Towers

The main features of the substructure are the two delta-shaped reinforced concrete towers approximately 120 metres high with a maximum width of 44.23 metres.



Two delta shaped towers of the ANZAC Bridge.

Construction of the tower legs commenced when the base segment of each tower was complete. The base segments consist of a solid block of concrete, 5.5 metres high and 6.5 metres wide, poured in two halves. The second segment was constructed with formwork tied back to a triangular frame anchored to the top of the base segment of each tower.

Concrete generally is quite high in resistance to corrosion, where resistance can be increased by expanding cover thickness, and general porosity of the specific concrete. The concrete used in the ANZAC Bridge's towers was specially cemented and made to have very **high resistance** to **corrosion** as it is crucial for it to retain its strength so as to keep the bridge up.

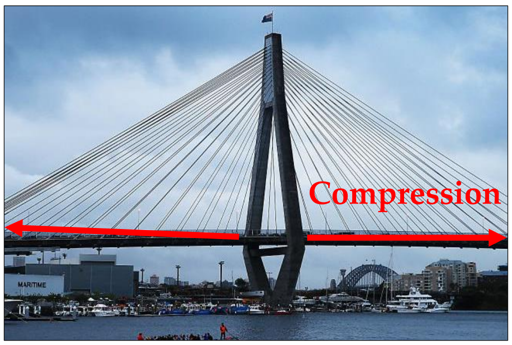
The towers within the ANZAC Bridge's structure are in **COMPRESSION** just like all cable stayed bridges.

Stress in towers of the ANZAC Bridge.

Deck

The deck was a 32.2 metre wide superstructure of cable-stayed spans which is a prestressed concrete open grillage deck system, consisting upon two longitudinal edge beams, cross girders at 5.17 metre spacings and a deck slab of 0.25 metre thickness.

Each deck segment weighs approximately 460 tonnes. During construction, as each deck segment is cast on one side of the tower it must be balanced by one on the other side. The deck segments towards land were cast first. The deck was erected by using cantilever methods, using a form traveller on one side of the pier (ie. water side) and a rolling form on the other (ie. land side).



<u>The deck within the ANZAC Bridge's structure are in **COMPRESSION** just like all cable stayed bridges.</u>

Stress in towers of the ANZAC Bridge.

Impact on Society

Past

Opening of bridge due to large ships coming into Johnston's bay.

The Glebe Island Bridge was historically part of the five bridges route connecting Sydney to the north shore and the route was important in connecting Sydney to Parramatta and the north shore from the middle of the nineteenth century, and for much of the twentieth century.[7] By 1980, up to 80,000 vehicles were crossing the Glebe Island Bridge daily and many ships whose heights were higher than the height from deck of the bridge to the water surface came in and out of Johnston's Bay. The need to keep opening the bridge for the ships to enter and leave created a notorious bottleneck (Traffic Jam). As a result, the society of the 1980's were troubled as they suffered massive delay's due to constant congestion on the roads leading up to the bridge.

Hence, the need for redevelopment of the Glebe Island Bridge lead to the construction of a second wider and higher, seven lane cable stayed bridge in 1989 now known as the ANZAC Bridge. This new bridge allowed the people of that time to experience much smoother traffic conditions with minimal congestion, which rarely only occurred during peak hours. The increase in height of the bridge meant that tall ships could enter Johnston's Bay without the bridge having to open and stop traffic flow, which allowed travel times between Sydney and the suburbs near Parramatta to decrease significantly, benefitting the society greatly.

Present

Man cycling on ANZAC Bridge's pathway improving his health and wellbeing.

At present, the ANZAC Bridge contains a pedestrian path / bikeway that runs along the northern side of the bridge, making possible a leisurely 30-to-40-minute walk for the general society from Glebe Point Road, down Bridge Road, over the Bridge and round Blackwattle Bay back to Glebe Point Road. This pathway is greatly used my members of society for physical activities such as jogging, cycling and simply walking, allowing people to improve the quality of their health and wellbeing. Furthermore, due to its appealing structure it attracts many tourists to visit Sydney and take photographs of the amazing views of the bay, which leads to economic growth of society as more and more tourists are drawn into the city.

Cameras filming activity on the ANZAC Bridge.

Some problems to society at present regarding the bridge is caused due to its strong historical and sentimental value towards the ANZAC's. The bridge is now seen as a target by the Australian government to terrorist attacks and hence, The Bridge is regularly patrolled by security guards as a counter-terrorism measure. Security cameras also monitor the walkway, which means that members of society using the bridge are constantly being filmed to prevent potential criminal activity.

Additionally, the bridge at present has traffic flowing slower due to the decrease in speed limit from 70 km/h to 60 km/h in January of 2005. This means that travel times at present between the Sydney city and Western suburbs have increased since 2005, a real downgrade to the rapidly advancing society. Furthermore originally, there were bus stops on the western side of the bridge. But, these stops were removed as there was a safety issue with buses pulling out into traffic which is travelling at speed, once the bus left the stopping area. This is both a positive and a negative to the quality of society, as people cannot directly stop on the bridge anymore but are now safer due to the fact that there is now a much smaller risk of a collision involving the bus on the Bridge.

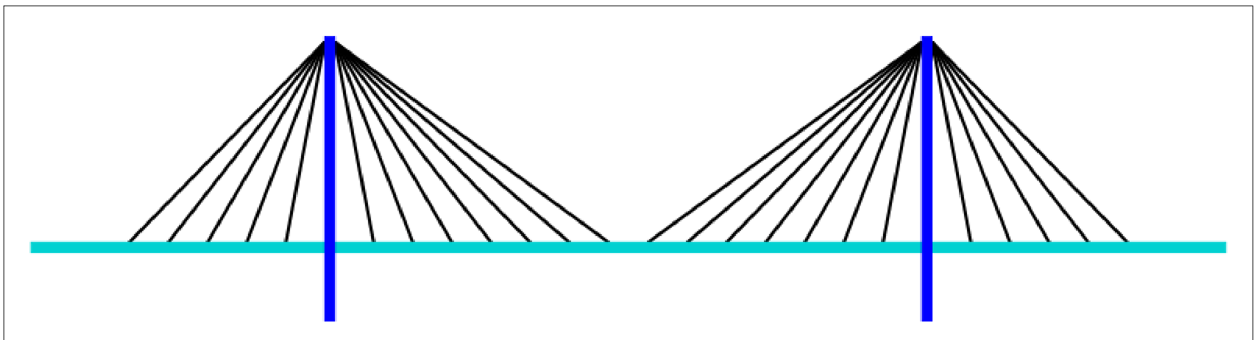
60 Speed Limit signs painted on the ANZAC Bridge road.

Type of bridge Design

The ANZAC Bridge design type is a **cable stayed bridge** designed by Percy Allan of the New South Wales Public Works Department who also designed the Pyrmont Bridge.

Overview

A cable stayed bridge has one or more towers (or pylons), from which cables support the bridge deck. A distinctive feature are the cables which run directly from the tower to the deck, normally forming a fan-like pattern or a series of parallel lines. This is in contrast to the modern suspension bridge, where the cables supporting the deck are suspended vertically from the main cable, anchored at both ends of the bridge and running between the towers. [10]



General structure of a Cable Stayed Bridge.

Origins of Cable Stayed Bridge

The modern cable stayed bridges that are present in today's society were developed after the Second World War and were not entirely a new concept as it was incorporated into some early model suspension bridges such as the Dryburgh Abbey Footbridge (1817) footbridge, The Albert Bridge, London (1873) and the Brooklyn Bridge, New York (1883) to give the deck rigidity.

Brooklyn Bridge.

In the twentieth century, early examples of cable-stayed bridges included A. Gisclard's Cassagnes Bridge (1899) and G. Leinekugel le Coq's bridge at Lézardrieux in Brittany (1924). In both bridges the horizontal part of the cable forces is balanced by a separate horizontal tie cable, preventing significant compression in the deck. [10]

Stromsund Bridge.

However, it wasn't till the 1950's that the first modern cable stayed bridges were built. Two German designers, Franz Dischinger and Fritz Leonhardt, working independently, built the first modern cable stayed bridges: Stromsund Bridge, Sweden (1955) with a 183 metre span and Dusseldorf Bridge, Germany (1957) with a 260 metre span respectively. These bridges utilised very few stay cables compared to bridges in today's society such as the ANZAC Bridge, due to lack of development in materials in the 1950 period. Modern cable stayed bridge structures tend to use many more cables in order to span the bridge longer and wider to ensure greater economy.

Materials used in ANZAC Bridge's Structure

Material 1 – Steel

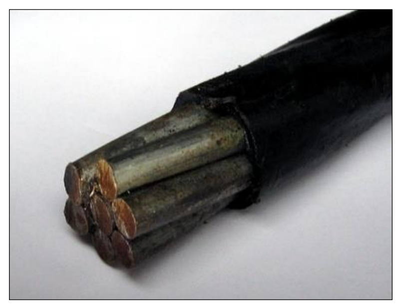
- **Properties:** The most important properties of steel are great formability and durability, good tensile and yield strength and good thermal conductivity. As well as these important properties one of the most significant characteristic of steel properties is its resistance to corrosion.
- **Implications within the ANZAC Bridge**: Each individual cable stay strand is made with high tensile and yield strength steel, meaning that as the bridge is subject to strong tensile forces, and the stay cables are able to resist the force. The really good thermal conductivity property is not necessarily important within the bridges structure as heat is not transferred through the cables. However, steels durability and resistance allows the bridge's structure to be very strong and last for years to come.
- **Environmental impacts:** Steel production has a number of impacts on the environment, including air emissions, wastewater contaminants, hazardous wastes, and solid wastes. All of the greenhouse gas emissions associated with steel production are from the carbon dioxide emissions related to energy consumption which directly relates to climate change.

Material 2 – Concrete

- **Properties:** Concrete has a relatively high compressive strength, but significantly lower tensile strength, and as such is usually reinforced with materials that are strong in tension (often steel). The elasticity of concrete is relatively constant at low stress levels but starts decreasing at higher stress levels as matrix cracking develops. Concrete has a very low coefficient of thermal expansion, and as it matures concrete shrinks. All concrete structures will crack to some extent, due to shrinkage and tension.

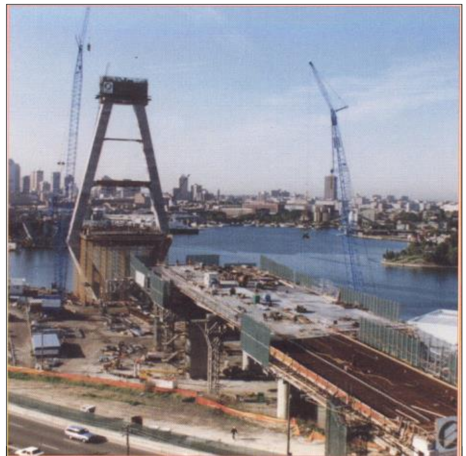
- **Implications within the ANZAC Bridge:** Both the deck and the towers of the ANZAC Bridge are in compression and hence require a high compressive strength material such as concrete to utilise in the structure. Since elasticity is low therefore the bridge is rarely ever subject to any stretching and the bridge's structure is very solid. Furthermore concretes low Thermal expansion levels means that the bridge has a tendency to not change in shape, area, and volume in response to a change in temperature, through heat transfer.
- **Environmental impacts:** A major component of concrete is cement, which has its own environmental and social impacts and contributes largely to those of concrete. The cement industry is one of the primary producers of carbon dioxide, a major greenhouse gas. Concrete causes damage to the most fertile layer of the earth, the topsoil. Concrete is used to create hard surfaces which contribute to surface runoff that may cause soil erosion, water pollution and flooding.

Material 3 – Polyethylene



- **Properties:** Polyethylene is of low strength, hardness and rigidity, but has a high ductility and impact strength as well as low friction. It shows strong creep under persistent force, which can be reduced by addition of short fibres. It feels waxy when touched.
- **Implications within the ANZAC Bridge:** The stay cables utilised in the ANZAC Bridge's structure were constructed from multiple steel wire strands surrounded by a black polyethylene sheath supplied by Vinidex Pty Ltd. Each individual wire strand was covered in polyethylene as it is an economical and no maintenance corrosion protection material which was cleverly used in the ANZAC Bridge's construction to prevent corrosion and increase durability, resulting in the bridge lasting for years more to come.
- **Environmental impacts:** The fact that polyethylene is durable means it degrades slowly. In addition, burning polyethylene can sometimes result in toxic fumes. Aside from trying to get rid of plastic, creating it can be costly to the environment as well. It takes large amounts of chemical pollutants to create plastic, as well as significant amounts of fossil fuels.

Important Facts



Construction of the great ANZAC Bridge.

The ANZAC Bridge is a tremendous structure with a wide range of development leading to collection of important facts. With the total length of the arterial measuring 3km and the total length of main span measuring 345m along with the width of 32m, it is obvious that much care has been taken during the construction process. A total 128 stay cables were utilised, whose combined length measured 5km with the longest stay cable at 188m and shortest at 88m.

Furthermore, immense amounts of materials were used during the construction of the bridge to give it the well-structured features it has.

- Total amount of concrete used was 35,700 cubic centres
- Total amount of reinforcing steel was 6,635 tonnes
- Total amount of prestressing steel was 760 km

Hence, due to these massive amounts of materials, the cost of construction of the bridge also was very high: approximately $170 Million.

Cars and other vehicles traveling on the ANZAC Bridge.

As years passed since construction, use of the bridge increased and by 2005 the number of vehicles crossing the bridge per day were 128,000 cars and it has only been exponentially increasing since then due to rising population.

The bridge is very historically significant as well, playing a huge part in commemorating the suffering of the ANZAC soldiers. On the 11th of November 1998, the bridge was renamed to ANZAC bridge from the Glebe Island Bridge. And on that same day the Australian and New Zealand flags were placed on the Tower Tops.

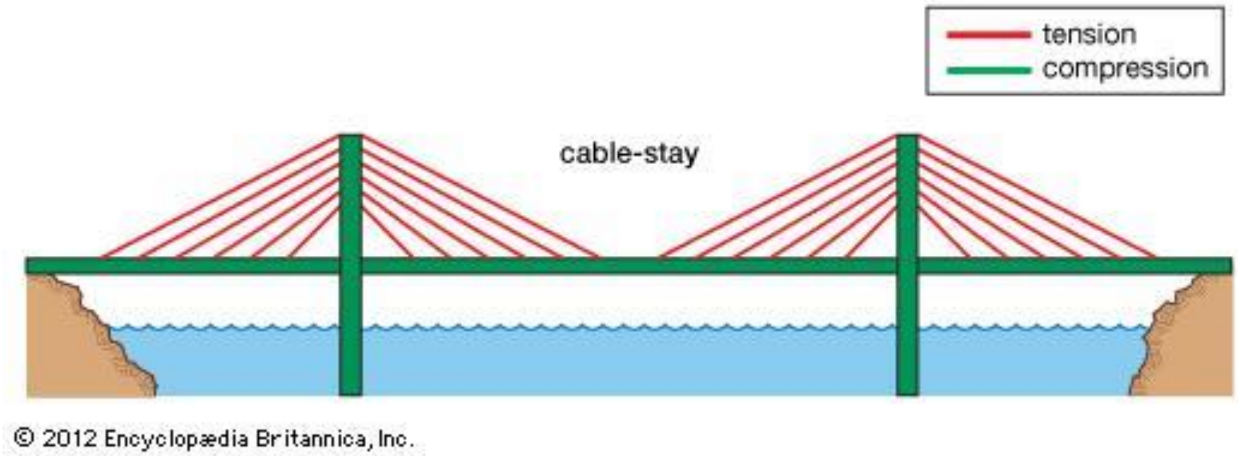
On the 25th of April 2000 Australian digger's dedication took place and 7 years later the New Zealand soldier's dedication took place.

The New Zealand Soldier Statue placed on the New Zealand soldier's dedication on the 27th of April 2007.

Extensive upgrade and maintenance needed to be taken place due to problems within the bridge. This upgrade and maintenance program cost approximately $61 million over the course of 3 years (2010 – 2013).

Appendix

Appendix A – Stresses on a Cable Stayed Bridge



Appendix B – Construction of ANZAC Bridge Timeline

The NSW Roads and Traffic Authority (RTA) decides to replace the Glebe Island Bridge in use since 1903	Mid 1980s
Bridge footings - steel casings for piles driven to the bedrock	1989
Bridge footings completed	Late 1990
Work stopped through lack of funding	1991 (recession)
Federal funding provided to restart construction	1992
Bridge structure commenced	April 1992
Western tower completed	November 1993
Eastern tower completed	September 1994
Western deck completed	July 1994
Eastern deck completed	June 1995
Two halves joined	24th July 1995

Appendix C – Statistics about the ANZAC Bridge

Total length of the arterial	3km
Length of bridge	805m
Length of main span	345m
Width of bridge deck	32m (250mm deep)
Height of towers	120m
Number of stay cables	128
Total length of stay cables	5km
Longest stay cable	188m 74 strands
Shortest stay cable	88m 25 strands
Total length of stay cable strands	18km
Minimum navigation clearance	27m
Total amount of concrete used	35,700 cubic metres
Weight of deck segment	460 tonnes
Total amount of reinforcing steel	6,635 tonnes
Total amount of prestressing steel	760km
Number of Traffic Lanes	8
Number of Vehicles crossing per day (Live camera on ANZAC Bridge)	128,000 (2005)
Cost of Construction	$170 million

Glossary of Terms

Abutments - parts of the bridge that resist the downward and outward forces of a bridge.

Beam bridge - a type of bridge that relies on the bending strength of the superstructure to support the road surface.

Bending moment - internal reaction to the bending effect of external forces bridge.

Bridge - a structure designed to provide safe passage across a gap.

Cable-stayed bridge - a modem bridging system using cables to provide additional support to the beam.

Span - the distance between piers or supports

Steel - an alloy of iron and up to 1.5% carbon

Tensile stress - internal reaction to an externally applied force that is trying to stretch the material

Toughness - the ability of a material to absorb energy when being deformed and thus resist deformation and failure

Ductility - the capacity of a material to undergo significant deformation or elongation under tensile load before fracture.

Concrete - a composite of aggregate and a hydraulic cement binder

Corrosion - the deterioration of material due to chemical changes brought about by its interaction with its surroundings

Civil structure - usually government-funded structure of substantial size constructed for use by the general public

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Image Based References

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- Cable strands within the polyethylene sheath and the drawing wheel: http://www.groveoz.info/images/strands1.jpg
- Anti-vibration: http://www.groveoz.info/images/IMG_4561a.jpg
- Cycling: http://www.dailytelegraph.com.au/newslocal/south-west/enjoy-stunning-views-along-the-scenic-routes-of-sydneys-top-10-bike-paths/news-story/9ea3b0c2d369356a1d755d96d1926e10
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