# THE BRIDGES OF SCOTLAND

**By James Macnaughton**

## INTRODUCTION

No one who has visited the country described in Hamish McCunn's evocative tone poem as "The Land of the Mountain and the Flood" can deny that its spectacular and very varied landscapes prove that it is one of the most beautiful countries in the world. As indicated, the two main elements involved are the ancient mountains and the rainy climate. The latter has resulted in countless thousands of streams and rivers flowing down from the high tops to the sea coasts, and these have had a major effect on the lives of the inhabitants, because trying to cross them, particularly when in spate after heavy rain, could be very dangerous and over the millennia many lives were lost.

To ease travel throughout the country fords or ferry boats were used where applicable, but obviously the more permanent and safer alternative was a bridge, and it is these ingenious and vital structures and their effect on Scottish history which I would like to look at in all their varying sizes, shapes and materials, some merely practical, others very beautiful. Bridges were and are so important that many towns and villages were named after them: Carr Bridge, Bridge of Don, Spean Bridge, Bridge of Earn, Coatbridge and most evocative of all – Rumbling Bridge – among many others.

Of the thousands existing, I am going to choose a selection of the more interesting, showing how the ingenious and skilful bridge builders overcame seemingly impossible natural obstacles.

## THE ORIGINAL WOODEN STIRLING BRIDGE 1297

**Figure 1. Artist's concept of wooden Stirling bridge.**

This was the first bridge over the River Forth 25 miles upstream from its Firth and the sea, and it was the reason why Stirling Castle, which overlooks the bridge from its rocky elevation, was such an important part of Scotland's defences, controlling as it did

the Gateway to the Highlands. Back in the 13th century it was a narrow wooden structure, allowing only two horsemen alongside each other when crossing, and this proved to be a vital element in the victory of William Wallace over the forces of King Edward1 of England in 1297. Wallace had camped with his troops on the North side of the Forth, and when Edward's men, led by the heavy cavalry, started to cross the bridge in the early morning, Wallace completely surprised them by attacking them straight away. The Scottish spearmen caused chaos among the English, the heavily armoured knights falling off the bridge into the river, and their bodies and horses preventing the foot soldiers from crossing. A famous victory for Wallace.

## SUSPENSION FOOTBRIDGE GOLF COURSE ABERFELDY PERTHSHIRE 1992

A complete change from a bridge of historical importance to one installed purely for the benefit of the members of Aberfeldy Golf Course. Why have I chosen this one? As will become apparent, the materials used in its construction were totally unique and a first in the world. The original golf course consisted of nine holes situated on a huge bend of the River Tay. In 1990 the Club bought land on the North bank of the river to create a further nine holes, and a bridge was needed to permit access.

**Figure2. Aberfeldy Golf Course suspended footbridge.**

Having limited funds, the Club engaged the talents of Dundee University's Engineering dept., and they came up with the brilliant idea of the world's first all-plastic footbridge which they would build as a research experiment and the students would provide free labour.

**Figure 3. Aberfeldy Golf Course footbridge.**

The Tay is Scotland's biggest river, and to bridge it required a three span clearance of 113 metres supported by two A-frame towers 17 metres in height and their cables. It was all made of pre-fabricated sections of fibre re-enforced plastic. This had the double benefit of being very light – a total weight of only 15 tons – and secondly needing little or no subsequent

maintenance. After 23 years of use and exposure to the Highland climate, it is weathering it all amazingly well. The entire project was completed for the very reasonable cost of £87,000.

## WADES BRIDGE OVER THE TAY, ABERFELDY, PERTHSHIRE 1733

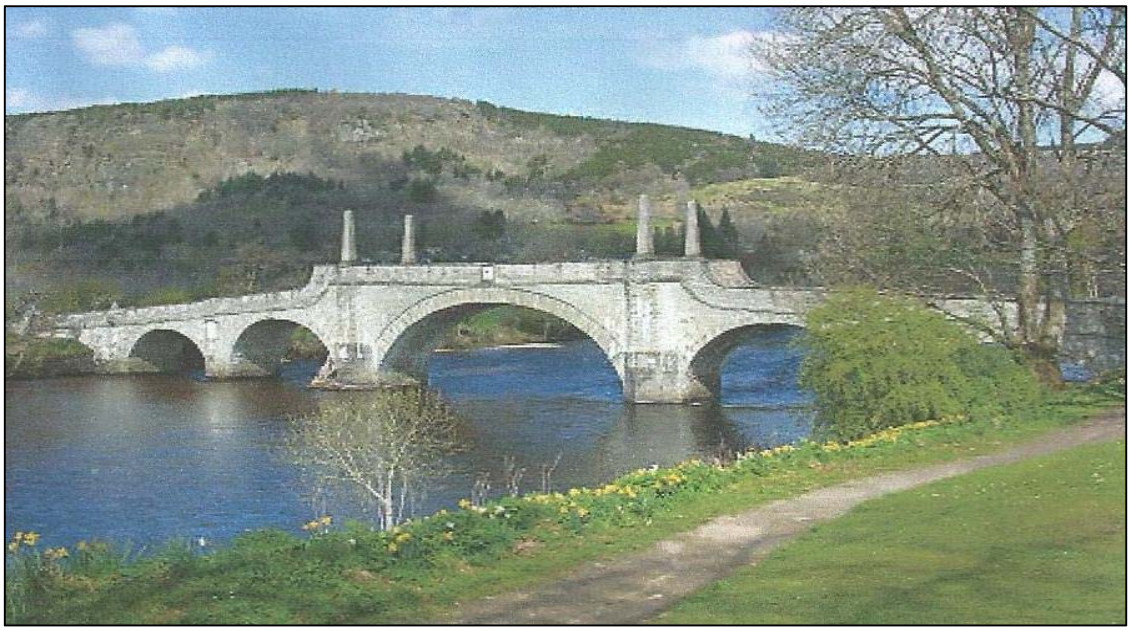


**Figure 3. Wades Bridge over the River Tay.**

In the aftermath of the unsuccessful 1715 Jacobite Rising, King George I commissioned General George Wade to build a network of 250 miles of new roads to provide much better overland communication between the Highlands and the Lowlands. This was done to ensure that a future Jacobite Rebellion was less likely to occur and, if it did, then Government troops could move around the country much more easily to suppress it. Ironically, these roads proved to be just as helpful to Bonnie Prince Charlie and his army in the 1745 Rising as they were to government troops. Obviously a large number of bridges were also necessary, and the pride of them all is the five arch stone bridge at Aberfeldy designed by William Adam, the father of Robert Adam, and built by General Wade and his men in 1733 at a cost of £4,000.

The piers and abutments of the bridge needed to be very strong and well founded, because the Tay sends more water down to the sea than any other British river, and when in flood during the spring snow melt, can rise 20 feet above its normal level. The stone used was chlorite schist from a quarry above Aberfeldy, which has the advantage of hardening when exposed to the weather, and, after nearly 300 years of constant use, even by the heaviest modern lorries, the bridge is as robust and handsome as ever. It is amazing that over 40 years General Wade and his successor Major William Caulfeild built more than 1,100 miles of well-constructed roads throughout the Highlands and parts of the Lowlands, too.

From 1733 70 1771 Wade's Bridge was the only bridge over the Tay between the sea and Loch Tay, because no less than five earlier bridges at Perth, the earliest in 1210 and the latest in 1621, had all been washed away by the overwhelming flood waters of the Tay augmented by the time it reached Perth by its tributaries Tummel, Braan, Isla and Almond. More

recently, the highest floods in 1814 and in 1993 had the Tay at an astounding 7 metres above its normal level. It was not until 1771 that the bridge at Perth designed by John Smeaton was opened, and it has survived the Tay floods until this day, and carries heavy modern transport.

## THE TAY RAIL BRIDGE OF 1878

The massive expansion of the railway network in Victorian times had a big effect in Scotland, and from about 1854 plans were discussed for a crossing of the Firth of Tay at Dundee to link Edinburgh and Aberdeen.

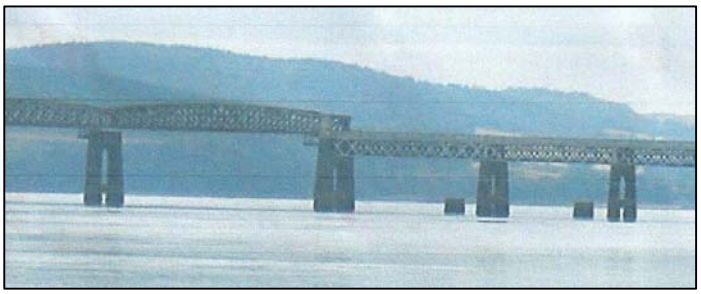
**Figure 4. Tay rail bridge today.**

The crossing required a bridge of 2.75 miles in length. This first bridge, which at the time of its completion in 1878, was the longest in the world, was designed by the famous railway engineer Sir Thomas Bouch, who had used a similar design for the Belah Viaduct on the South Durham and Lancashire Union railway in Cumbria in 1860.

**Figure 5. Picture of the Tay rail bridge the day after its failure.**

The construction involved the use of single piers of brick supporting lattice girders of cast iron with a single rail track, the girders being high enough to allow sailing ships to travel underneath on their way up the Tay to Perth. As is often the case, construction delays meant that to open the bridge as expected in September 1878, final sections were rushed into place. The Board of Trade Inspection done by Major General Hutchison concluded that the structure was satisfactory, that a 25 mph speed limit should be imposed, and added that he would like to inspect the bridge again when a train was crossing in a high wind. Prophetic words, because on 28 December 1879 a strong Westerly gale was blowing at right angles to the bridge and a train carrying 75 passengers and crew plunged into the icy waters of the Tay, when a section of the bridge collapsed and all were lost. It remains the worst bridge disaster in Britain. William McGonagall, a local Dundee poet, known and loved for his lamentably naïve verses, was inspired to write:

**Figure 6. Northern segment of second Tay Bridge, showing stumps of the original bridge's piers poking above the Tay.**



"Beautiful railway bridge of the silv'ry Tay
Alas I am sorry to say
That ninety lives have been taken away
On the last Sabbath day of 1879
Which will be remember'd for a very long time.

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Oh! The ill-fated bridge of the silv'ry Tay,
I now must conclude my lay
By telling the world fearlessly without the least dismay,
That your central girders would not have given way,
Had they been supported on each side by buttresses
At least many sensible men confesses
For the stronger we our houses do build
The less chance we have of being killed."

A new double track bridge, designed by W. H. Barlow and built by William Arrol Ltd., was constructed between 1883 and 1887, with double piers and much stronger steel girders rather than cast iron, and it still carries the trains of today. However14 men lost their lives during its construction, mostly by drowning. In 2003 over 1,000 tons of bird droppings were scraped off the ironwork lattice using hand tools!

## THE FORTH RAIL BRIDGE 1890

Sir Thomas Bouch had submitted a design for the rail bridge over the Firth of Forth, but when the Tay Bridge disaster occurred, he went into disgrace and died a few months later. Sir John Fowler and Benjamin Baker were given the job of designing what is still probably the most famous bridge in the world - indeed one of the Wonders of the World - and, after what happened to the Tay Bridge, they specified that their bridge would have to withstand five times the wind pressures allowed for there. At the time of its building, the Forth Bridge shattered records for the largest volumes of masonry (140,000 cubic yards) and steel (54,000 tons) ever used in a bridge as well as the highest, longest, deepest and most widely spanning cantilevers. It has a total length of 8,094 ft., an overall height of 361 ft. and a clearance for shipping of 150 ft. at high water.

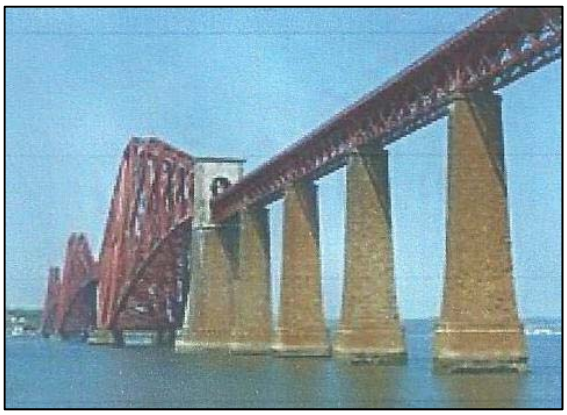


**Figure 7. Forth Rail Bridge.**

The Quebec Bridge in Canada (1901) is the only one in the world with a longer single cantilever span. The Forth on the site is up to 200 feet deep, so it would have been impossible to construct the numerous piers needed for a series of truss spans as used in the Tay Bridge. So the engineers switched to the use of steel with its greater tensile strength (rather than cast iron) and the cantilever principle, hitherto unknown in Britain. This allowed them to have only three main quadruple piers, two in the deep water and one on the island of Inchgarvie in the middle of the Firth. The cantilever arms were built out from the steel towers – each on four granite piers - simultaneously in each direction to balance the forces involved. At each end of the bridge are stone and steel viaducts which are major bridges in their own right, each 1,260 ft. long and 130 ft. above high water.

Nowadays, because of better paints used in 2002, the repainting of the bridge only requires to be carried out every 20 years rather than non-stop. This bridge was obviously over engineered when it was built, as a reaction to the Tay Bridge disaster, but 125 years later it is still effortlessly carrying the heavy modern trains, and up to 200 trains cross the bridge on its dual tracks each day, with a speed limit of 50 mph. The bridge cut 3 hours from the London to Aberdeen route via the West coast railways. Sadly, 73 workers died during its construction.

## THE FORTH ROAD BRIDGE 1964

From the reign of King Malcolm III the only crossing of the Firth of Forth was a ferry established in the 11th. century by his Queen Margaret, hence Queensferry. This was inaugurated to transport pilgrims from Edinburgh to Dunfermline Abbey and to Saint Andrews. This ferry lasted for over 800 years, converting to vehicular traffic, and by the 1950s the four ferryboats were making 40,000 crossings annually and carrying 1.5 million passengers. At that time the nearest bridge upstream was 15 miles away at Kincardine on Forth, so with the ferry queues getting longer and longer pressure grew for a bridge to be built.

**Figure 8. Forth Road Bridge across the Firth of Forth.**

Construction started in 1958 through a combination of Sir William Arrol, the Cleveland Bridge Co and Dorman Long. At a cost of £11.5 million they built the longest steel suspension bridge in Europe, along with nine miles of dual carriageway approach roads including twenty-four individual bridges. If the Forth Rail Bridge impresses with its sheer massive solidity, this lovely slender suspension bridge is a memorably beautiful structure in contrast which makes one marvel at man's ingenuity in creating something on such a gigantic scale.

The central span is 3,300 ft. long, the two side spans each 1,340 ft. long and the approach viaducts are 827 ft. on the North side and 1,440 ft. on the South side. With a total length of 8,240 ft. it was in 1964 the longest suspension bridge span outside the U.S.A., and the fourth longest span in the world. In its first year it carried 2.5 million vehicles, but since then it has increased steadily to around 21.4 million vehicles in 2008. The bridge had been constructed to carry 30,000 vehicles per day in each direction, but by 2010 this had risen to 60,000 vehicles, and concern was raised about the structural wear and tear of the bridge. Its lifespan had originally been planned at 120 years. Corrosion in the main cables was discovered, caused by the damp, salty sea air, resulting in an 8-10% loss of strength. Future projections estimated that this would accelerate with traffic restrictions being implemented and possible full closure by 2020. A de-humidification programme started in 2006 to slow the rate of corrosion by installing a system to keep the air in the voids between the strands in the main cables at a humidity level of less than 40%.

Faced with the threat of a possible full closure of the bridge, with all the massive economic and transport chaos that would cause, in 2007 the decision was taken to build a replacement bridge and its construction started in 2011. It is to be a cable-stayed bridge of 1.7 miles overall. The approach roads will link with the M.9 and M.90 motorways on each side of the Firth. It is well under way and will be another beautiful slim structure, which is scheduled to open in December 2016.

## THE KINCARDINE BRIDGE 1936

As mentioned, it is sited 12 miles up the Forth from the Forth Road and Rail Bridges and is interesting because it was constructed as a Swing Bridge to allow larger ships to sail upstream to the small port at Alloa. After 1988 the swing section was permanently closed. In 2008 the dual carriageway viaduct type Clackmannanshire Bridge was opened just upstream, bypassing Kincardine to ease the traffic hold-ups on the old bridge and those through Kincardine itself.

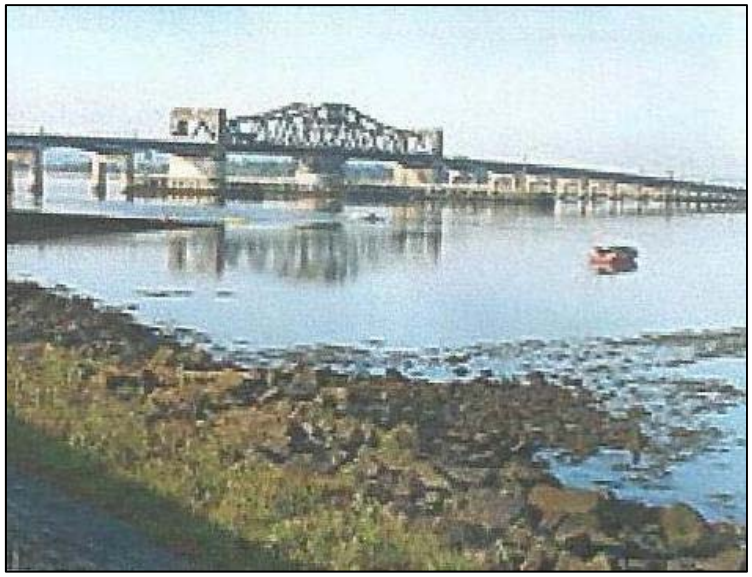


**Figure 9. Kincardine Bridge.**

## THE GLENFINNAN VIADUCT ON THE FORT WILLIAM TO MALLAIG RAILWAY 1901

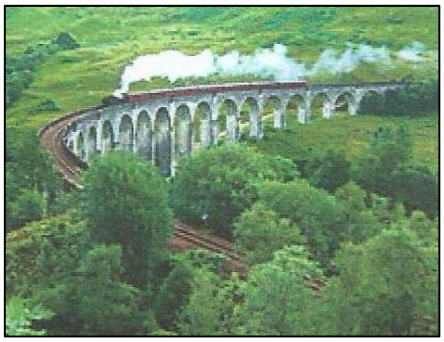


**Figure 10. Glenfinnan Viaduct.**

When the Fort William to Mallaig West Highland Railway was planned in 1896, on a part of the route at the head of Loch Shiel a lengthy viaduct to cross the valley of the River Finnan was required, and it is interesting for the material used in its construction. It was designed by Sir Robert McAlpine and Sons, whose owner, Robert McAlpine, was nicknamed "Concrete Bob" for his innovative use of mass concrete. It was used for the viaduct because the local hard schist stone was very difficult to work. There are 21 spans, each of 50 ft. It is the longest concrete bridge in Scotland at 416 yards, and it crosses the River Finnan at a height of 100 ft. Unlike re-enforced concrete, the mass concrete contains no metal re-enforcements and it is made by pouring very fine aggregate into framework. This makes it very strong in compression, but weaker in tension. The viaduct has been made famous by its use as a location in several films and TV series, including Ring of Bright Water, Monarch of the Glen, Stone of Destiny and, of course the four Harry Potter films for the Hogwarts Express.

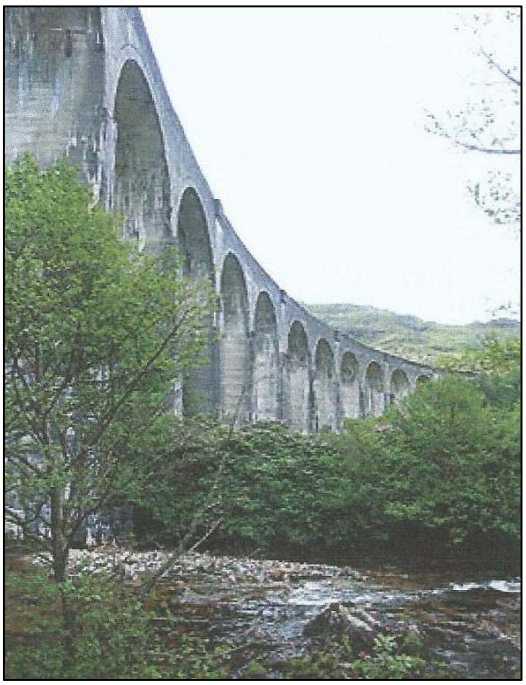


**Figure 11. Glenfinnan Viaduct from below.**

## THE AVON AQUEDUCT NEAR LINLITHGOW 1821

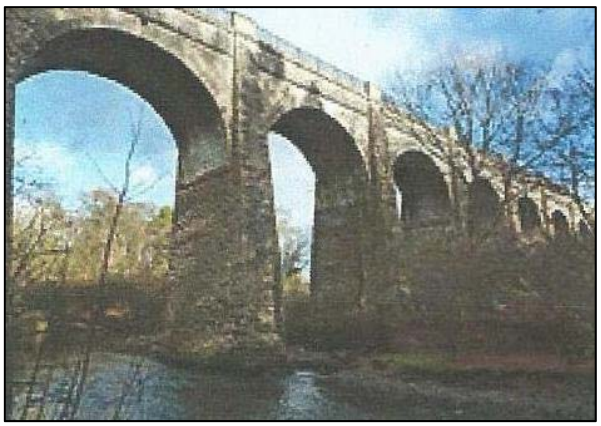


**Figure 12. Avon Aqueduct.**

This is a navigable aqueduct which carries the Union Canal between Edinburgh and Glasgow over the River Avon near Linlithgow using 12 stone spans at a height of 86 ft. Designed by Hugh Baird with advice from Thomas Telford, it uses a trough of cast iron to ensure that there were no water leaks and also to enable the viaduct to be built using

less heavy masonry. At 810 ft. long it is the longest and tallest aqueduct in Scotland and the second longest in Britain.

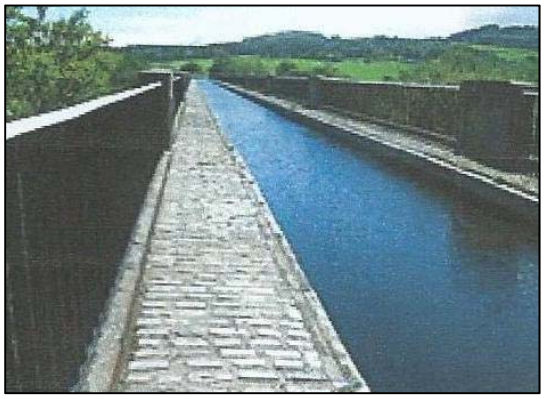


**Figure 13. Avon Aqueduct from above.**

## THE FALKIRK WHEEL MILLENIUM PROJECT 2000

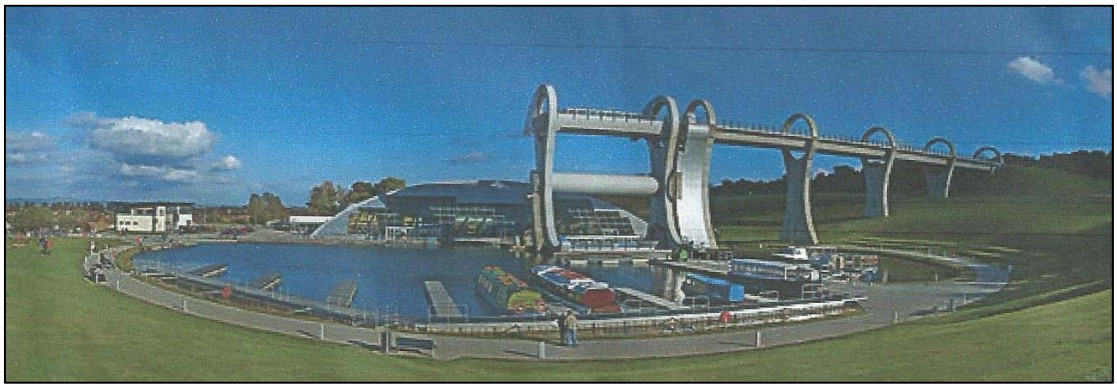


**Figure 15. Panorama of Falkirk Wheel.**

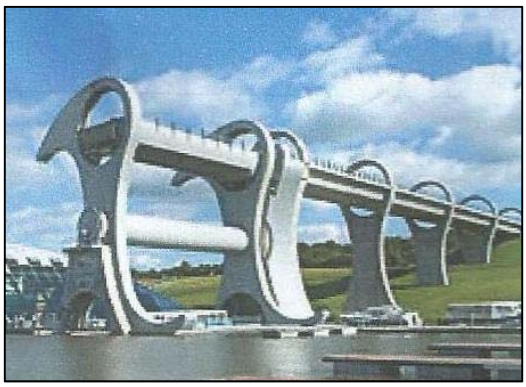
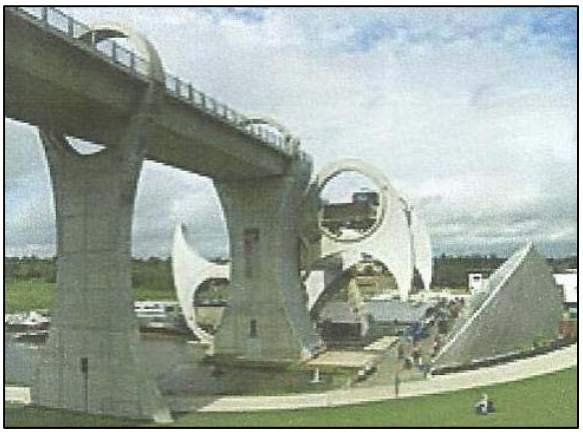


**Figure 16. Falkirk Wheel from lower level.**

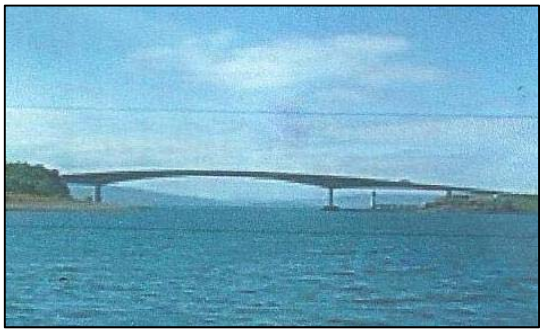
Although not strictly a bridge, I could not resist including this marvellous piece of engineering, which was one of the best of the Millennium Projects. The plan was to re-join the Union Canal to the Forth and Clyde Canal at Falkirk, which had originally been achieved through the use of a set of 11 locks at Camelon. The very imaginative way in which this was done was through the world's first rotating boat lift, shaped like a double headed Celtic axe, with a diameter of 115 ft. It was designed to lift a cassion of 500-ton weight containing water and/or up to four, 22-metre-long canal boats 79 ft. up, while another counterbalancing cassion of equal weight was lowered. The cassions are geared to turn with the Wheel and remain level by moving in the opposing direction, thus cancelling the effect of the Wheel's rotation.

**Figure 16. Falkirk Wheel working.**



Because the two cassions are in balance, it only requires a very small amount of electric power to raise the cassion, roughly the same as boiling 8 kettles of water Watertight lifting doors at each end of the cassions allow ingress and egress of the boats at the top and bottom of the cycle. The Wheel proved to be a visually stunning and very sophisticated example of modern engineering, and a very popular visitor centre has been established, allowing visitors to ride up in the cassion, travel along the canal through a tunnel and then return and descend to the lower level again. The Royal Fine Art Commission consider it to be "a form of contemporary sculpture". It was formally opened by the Queen on 24 May 2002, completing the link between the two canals which had been broken for nearly 70 years. The total cost was £85 million.

## THE SKYE BRIDGE FROM KYLE OF LOCHALSH TO KYLEAKIN 1995



I could not close without mentioning the most romantic bridge of all!

**Figure 14. Skye Bridge.**

"Speed bonny boat, like a bird on the wing
'Onward!' the sailors cry;
Carry the lad that's born to be king
Over the sea to Skye."

A bridge over the sound between Kyle of Lochalsh and Kyleakin on Skye had been proposed back in the 19th. century, but shelved because of the island's remoteness and small population. Ferry services had been in operation from Kyle of Lochalsh to Kyleakin since 1600. In 1989 plans were agreed for a toll bridge and a single span concrete arch supported by two piers resting on caissons in Lochalsh and using the small island Eilean Bhan as a stepping stone. A beautiful slim curved silhouette was the result. Construction began in 1992 and the bridge was opened in 1995. The tolls were very unpopular and by 2004 a round trip cost £11.40, much more than the round trip price charged by the Forth Road Bridge, a crossing of twice the length.

Skye locals were particularly angry and many refused to pay. Around 500 were arrested and 130 of those were convicted of non-payment. By December 2004 the Scottish Executive had decided to purchase the bridge for £27 million and the charging of tolls ceased forthwith. They had raised £33 million whereas the operating costs only totalled £3.5 million. Those still wishing to enjoy the more romantic sail over the sea to Skye can do so using the ferry

from Mallaig to Armadale in the South of the island or the smaller one during the summer months from Bernera to Kylerhea by taking the Ratagan road to Glenelg off the A.87 Kyle of Lochalsh road.

## CONCLUSION

So there we have it! A small selection of the Footbridges, Road Bridges, Rail bridges and Canal Bridges which radically changed travelling throughout Scotland, and we have a lot to thank the endless stream of talented Scottish bridge designers and builders, who have eased the weary traveller through their ingenuity and skill. Among them was my Father – Alexander Macnaughton BSc. Ed., AMICE – who served with the Royal Engineers in the latter years of World War I and subsequently worked with the Cleveland Bridge Builders at Darlington, until his ailing father pleaded with him to give up his career as a Civil Engineer to join the family business in Aberfeldy. His proudest achievement was to be elected AMICE – a Fellow of the Royal Institution of Civil Engineers.