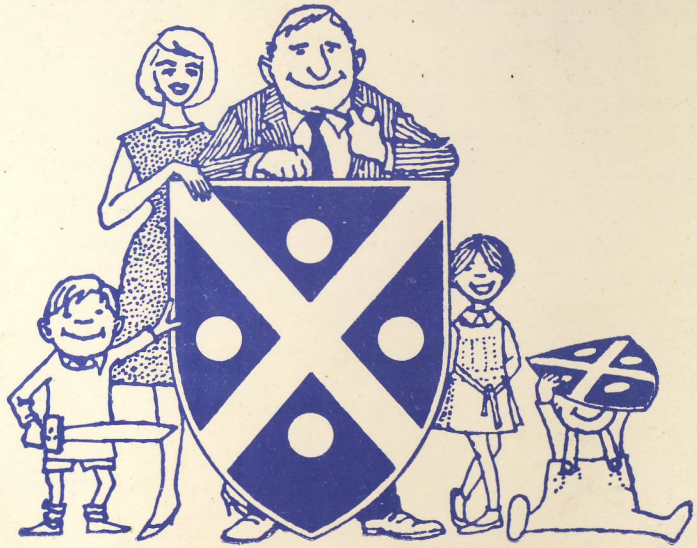
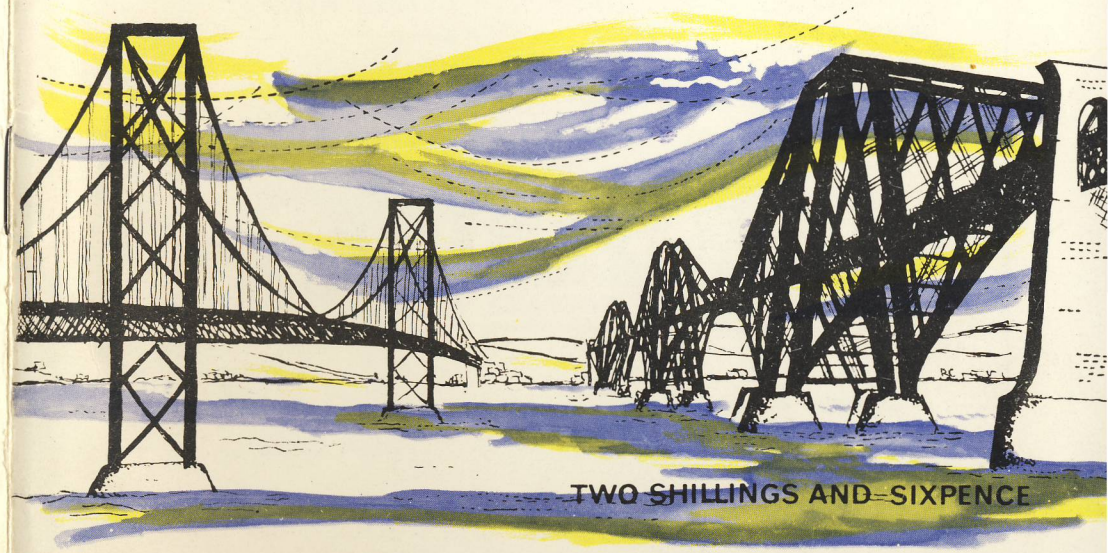
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A Tale of Two Bridges

by

ALBERT MACKIE

FOREWARD

by

W: A. NICHOLSON, O.B.E.
Director,
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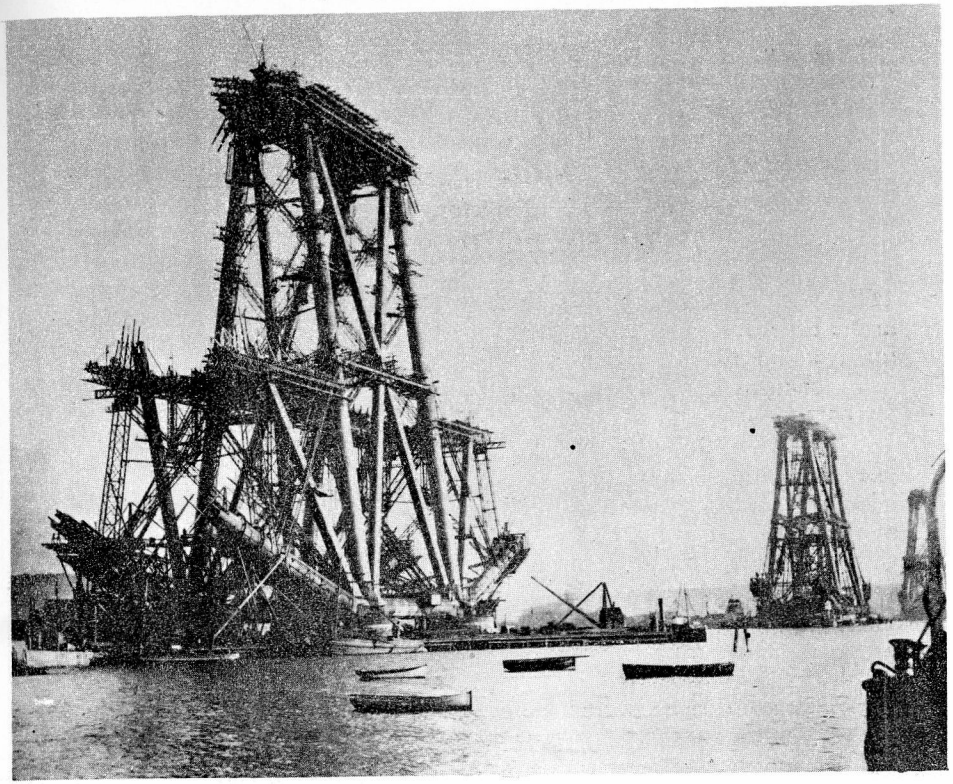
THIS fascinating Tale of Two Bridges records the modern developments in the provision of transport facilities which have existed at Queensferry for over one thousand years. Scotland and the world have undergone many changes since Queen Margaret sailed across the narrow channel to chart the first link between the north and south of the river.

Modern science has given us two of the world's greatest structures, one fascinatingly modern and the other a master achievement of Victorian railway engineers ; and the ferries that have so faithfully and so regularly carried millions of people throughout the centuries, latterly with their cars, now pass into history.

The massive, spectacular, and really beautiful road bridge, now opened, marks the passage of time and symbolises the new era in which we live. There may be some who doubt its value and the extent to which it will be used. I for one have no doubts.

It, and its sister bridge across the Tay, will soon be numbered among Scotland's greatest assets, and, with the Forth Railway Bridge, will undoubtedly be great tourist attractions.

The passage each year of a million cars over each of the new road bridges is not, I am sure, an over-optimistic estimate. These bridges, basic to future Scottish development, will play a major part in meeting the demands of Scotland's fast rising tourist industry.



BUILDING THE FORTH RAILWAY BRIDGE

TWO great bridges span the Forth side by side. Each of them is a masterpiece of engineering. Together they constitute one of the wonders of the world.

This is the story of these two bridges. It is a tale which has its beginnings far back in times when such feats of engineering were unthinkable, and yet when the crossing of this waterway at this point was already regarded as most important.

Scotland has a rugged coast which makes distances by land greatly out of proportion to the size of the country. Bridges are vital to its economy.

Small and out-of-the-way as it is, on the north-western edge of Europe, Scotland has always been a magnet for visitors from abroad, and, unlike the tourists of today, these visitors were not always welcome.

Waves of invaders from Europe—Celts, Romans, Scandinavians and Germanic tribes—gravitated to the Firth of Forth. The Romans made their camps on these shores and built their wall nearby. Romanised Britons fought a losing battle for the district against the Angles. Eventually Dunfermline and Edinburgh, on the two sides of the Forth, became the headquarters of the nation of Scotland. In all these periods the crossing which became known as the Queensferry Passage was a natural link between Fife to the north and the Lothians to the south.

Although Queensferry takes its name from King Malcolm Canmore's English bride, Queen Margaret (the Saxon Saint), who crossed regularly from 1068, and the first reference to the name is dated 1164, the strait was a natural ferry passage and was well developed in that way by early in the twelfth century.

In 1130 it is referred to as " the passage and ship of Inverkeithing " in a document granting its control to the monastery of Dunfermline. In 1164, King Malcolm IV granted the monks of Scone and their men free passage at the Queensferry, and from then on this name gradually takes the place of the name Inverkeithing, though this remains the name of the neighbouring harbour.

BOATS TO BRIDGES.

Towards the end of the thirteenth century the ferrying was leased by the church to other operators at a rent of eightpence an oar. Until early in the nineteenth century Scotland remained more or less content with ferry arrangements which developed with the steady progress in ship design from rowing through sail to steam, though even in the eighteenth century there were visionaries who considered that this would be an ideal part of the waterway for the erection of a bridge.

As the railway had not yet been introduced, the idea for a road bridge actually preceded the conception of a railway bridge. It was how to get horse-drawn transport across that occupied the minds of the pioneers.

Bridge visionaries were usually laughed at, and even the calculations of men skilled in bridge-building were concentrated on the improvement of the ferry arrangements. In May 1809, when the ferry was disposed of to trustees representing national and local interests for the sum of £8,673 13s 10½d, the bridge and road engineer, John Rennie, was consulted and recommended piers and large boats.

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1749 *William Younger set up his first brewhouse in Leith. Later set up several more. Became well known both as excise-man and brewer. Founder of Younger dynasty—famous for their Scotch Ales and Sweet Stout.*





1890 *The Newcastle Breweries Ltd was formed to take over the businesses of various brewers and wine and spirit merchants in Northumberland and Durham. Famous for their Newcastle Brown Ale,*





1856 *William McEwan founded his Brewery—now famous for McEwan's Export and McEwan's Pale Ale.*

1930 William Younger & Company Ltd and William McEwan & Company Ltd, Scotland's two largest and most famous brewers, amalgamated to form Scottish Brewers Ltd.

1960 The Newcastle Breweries Ltd merged with Scottish Brewers Ltd to form Scottish & Newcastle Breweries Ltd. This combined Company now owns nearly 2,000 public houses, off licenses and hotels throughout Scotland & England.

1964 Scottish &'Newcastle Breweries Ltd is now among the half dozen largest brewers in Great Britain. But perhaps even more important than its size—its products are renowned for quality in very many countries throughout the world. To brew a first class beer takes a lot of experience. And experience takes a lot of time. There are over two centuries of time to guarantee the quality of S & N products. It's this high quality and the standard of its many first class hotels that have created the reputation of Scottish & Newcastle Breweries Ltd., as thirst quenchers—and hosts —to the nation.

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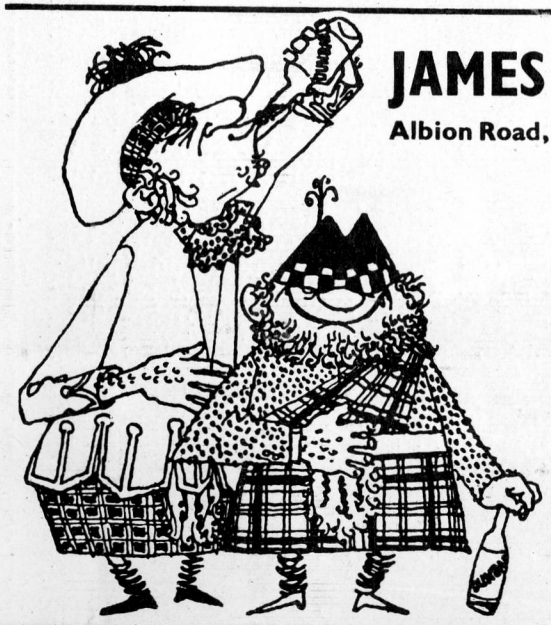
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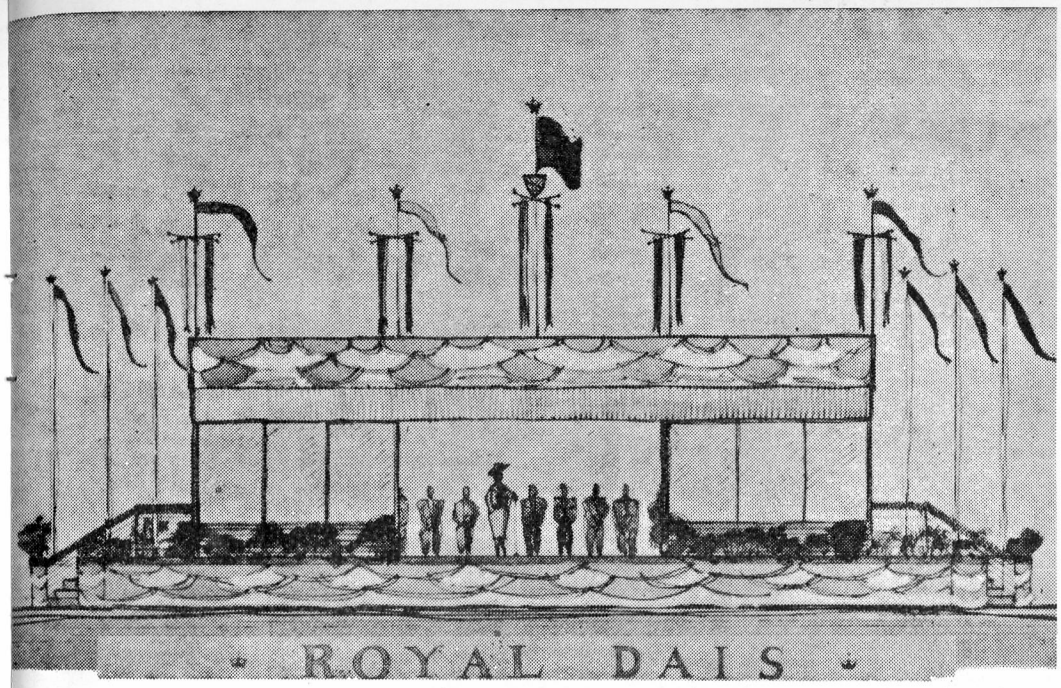


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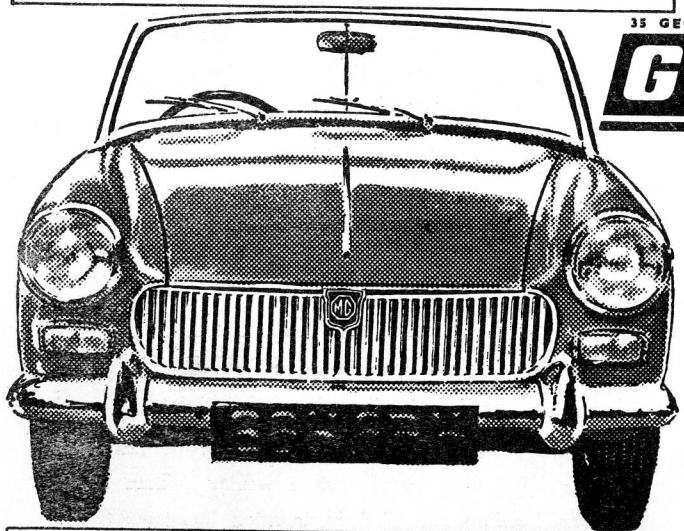
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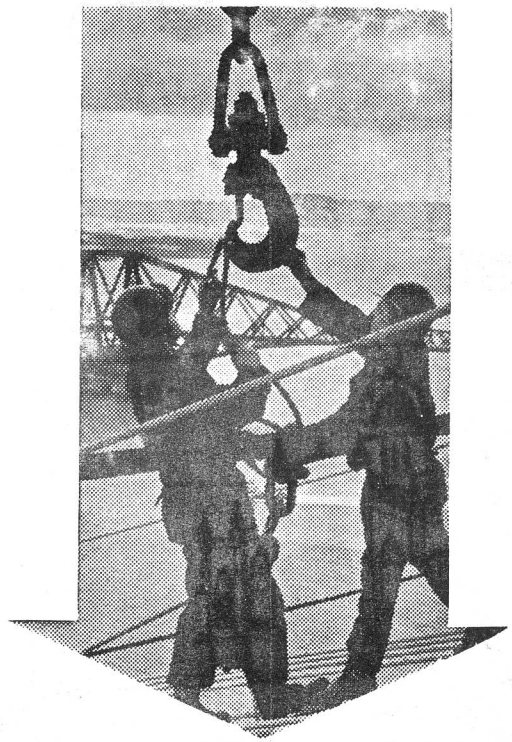
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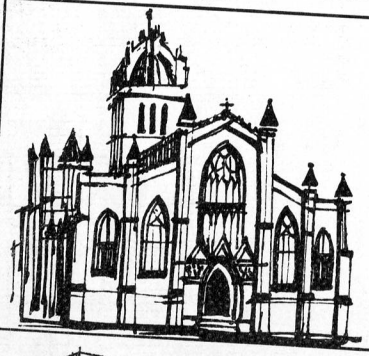
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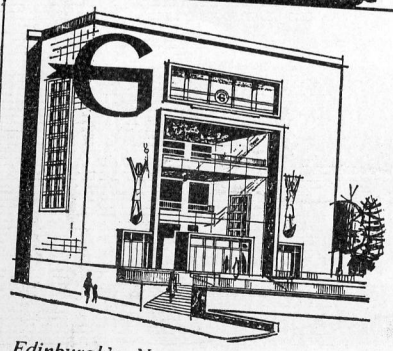
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RAILWAY BRIDGE: GIANT CANTILEVERS TAKE SHAPE

In 1820 a specially built vessel called the Queen Margaret, costing £2,500, was introduced. Thomas Telford, another famous engineer, road and bridge builder, made further recommendations on pier extensions in 1828.

More vessels were employed on the crossing. Parliament passed Acts, in 1838 and 1848, for the improvement of the Passage. By this time the railways were keenly interested, and the 1848 Act provided for their participation in the running of the ferry.

Thomas Bouch, designer of the Tay Bridge, had a scheme in 1851 for ferrying trains by steamer across the strait without their engines. The North British (Edinburgh, Dunfermline and Perth) Railway Act of 1863 envisaged the ferrying of carriages and engines. Nothing came of these projects, though the North British Railway Company did purchase the ferry in 1863.

Ferry boats operated by the railway company and by their tenants continued to be an important means of crossing even after the erection of the Railway Bridge. From 1933 onwards the lease was held by Denny, Dumbarton.

They put the Queen Margaret into service in 1934 and added the Robert the Bruce, the first all-welded ship built in Scotland, the same

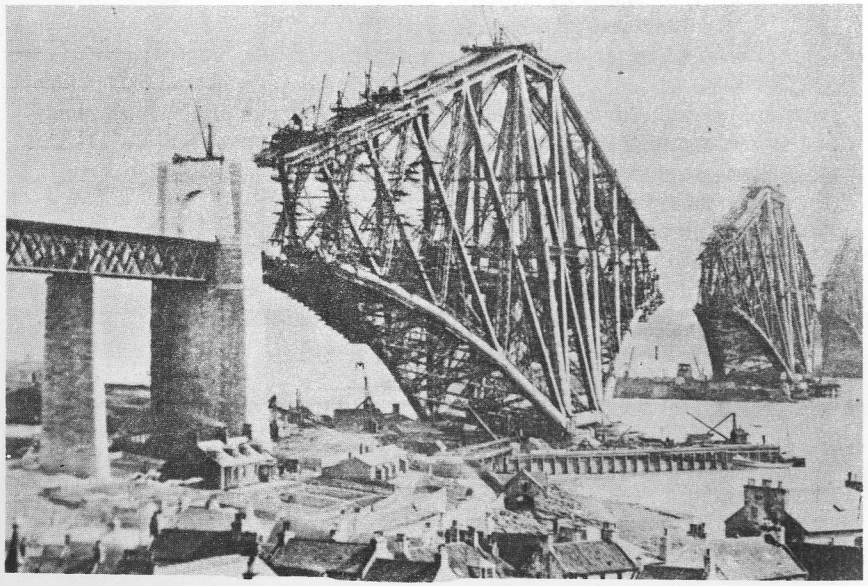
year. Mary Queen of Scots followed in 1949 and Sir William Wallace in 1956. Dr John Mason, of South Queensferry, wrote a booklet, " The Story of the Water Passage at South Queensferry," which was published by William Denny & Brothers Ltd., Dumbarton, in June 1962, and sold on the ferries.

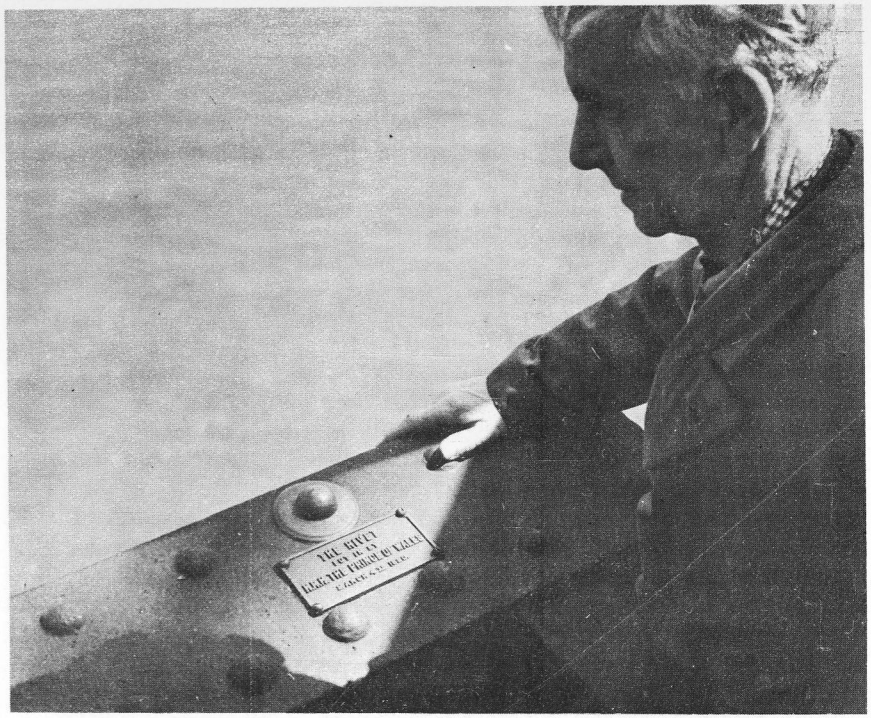
He mentioned that in 1474 the charges for crossing were fixed by Parliament at one penny Scots for a man and two pence for a horse. By the mid-1700's this had risen to 1s. 6d. Scots for a man and 4s. for a horse. In 1925 the fare was 10s. for a motor car, 2s. 6d. for a motorcycle and 5s. for a motorcycle with sidecar, but before the ferries came to the end of their long service the fare for a car was 8s. 6d. maximum, and motorcyclists were charged 2s. 3d. or 4s. with sidecar.

BRIDGES AND TUNNELS.

Bridges have been considered at latest since 1740, and Telford regarded Queensferry as the likeliest point for such an undertaking. The line by Inchgarvie was also chosen for a tunnel proposal of 1790. A suspension bridge using the same island was suggested in 1818 by an Edinburgh civil engineer, James Anderson.

BELOW: VIADUCT AND CANTILEVER JOIN UP





PRINCE OF WALES' RIVET ON THE RAILWAY BRIDGE

Thomas Bouch's suspension railway bridge plan for which powers were obtained in 1865, chose a crossing more to the west, from Blackness to Charlestown. As Bouch was the builder of the first Tay Bridge, which collapsed disastrously on December 28, 1879, his Forth Bridge scheme, on which work had begun, was abandoned.

Four railway companies sought and obtained new powers in 1882 to build another design of railway bridge at Queensferry. It was the conception of Sir John Fowler and Sir Benjamin Baker, and the contractors were Tancred, Arrol & Co. Ltd. Work started in January 1883.

The Bridge was completed in March 1890. It was opened by the Prince of Wales, later King Edward VII, and a plate on the Bridge indicates " The last rivet put in place by H.R.H. The Prince of Wales, March 4th, 1890." The Forth Railway Bridge cost £3,000,000 to erect and employed at one time nearly 5,000 workmen in its construction. For the following facts and figures I am indebted to British Railways.

FORTH RAILWAY BRIDGE

Foundations. Boulder clay and freestone support the foundations of the South Approach viaduct. The South Queensferry Pier is on boulder clay and the Inchgarvie Pier, Fife Pier and North Approach viaduct are on Whinstone rock. The main cantilevers are supported in each case on four circular granite-faced masonry piers. The diameter of the highest pier is 70 feet at the base and 49 feet at the top. At each pier the steel superstructure is anchored to the masonry by 48 steel bolts, $2\frac{1}{2}$ inches in diameter and 26 feet long.

Cantilevers. There are three double cantilevers. These are known from their position from south to north as the Queensferry, Inchgarvie and Fife Cantilevers. The shoreward arms of the **Queensferry and Fife Cantilevers** do not rest on, nor are they fixed to, the approach viaducts. At each of the two extremities are counterpoise weights of 1,000 tons. These balance the maximum possible live loads with the addition of half the weight of one central girder. On the **Inchgarvie Cantilever** the weight of half a central girder is carried at each end. So far as the dead load is concerned, the balance is perfect. Yet a train coming on at either end would upset this balance. For this reason the columns on the Inchgarvie Pier have a much longer base than the columns on the Fife and Queensferry Piers.





A Famous British Railways Poster

What are called the " vertical " columns, if seen from a viewpoint looking along the centre line of the bridge, are discovered to have an inclination of 1 in $7\frac{1}{2}$ which is maintained throughout the cantilever bridge. These " vertical " columns are 12 feet in diameter.

The **central girders,** 346 feet long, have fixed bearings on the ends of the Fife and Queensferry Cantilevers and expansion bearings formed by rocker posts at the ends of the Inchgarvie Cantilever arms. Here a total movement of 10 inches expansion and contraction occurs. There is also provision for expansion at the shore ends of the Fife and Queensferry Cantilevers, where the total movement is 5 inches.

Two **railway tracks** are carried on the internal viaduct, which is formed by two latticed girers, 16 feet centre to centre, with cross girders about every 11 feet, and is supported from the main cantilever structure by cross girders and trestles.

Materials. The materials employed in the construction were

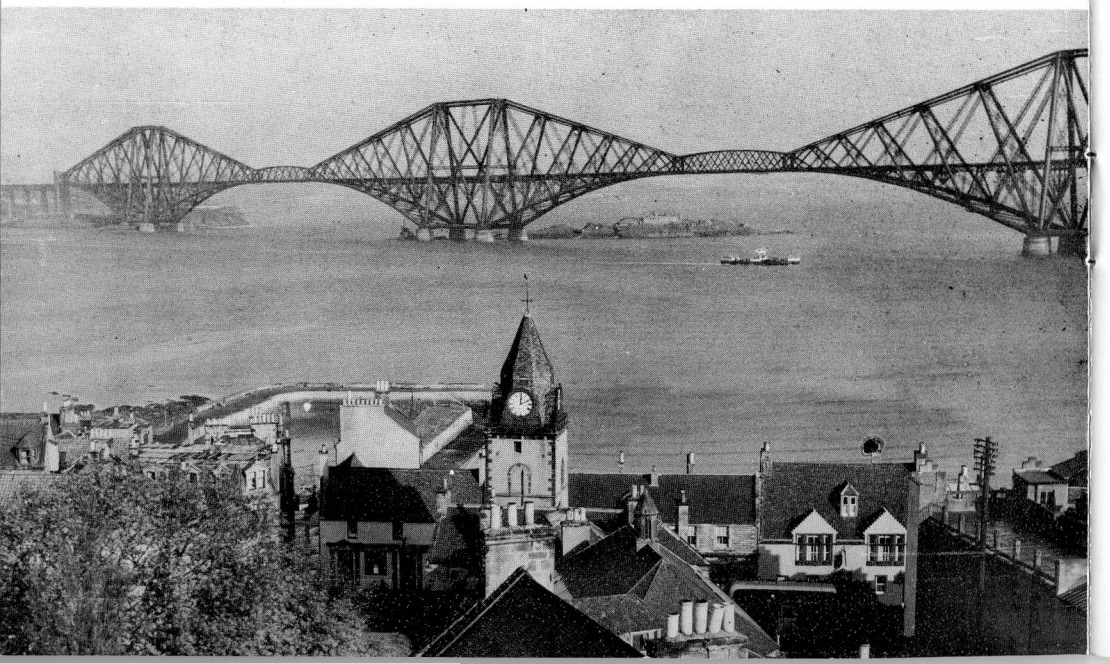
Steel		54,160 tons.
Masonry—	Granite	740,000 cubic feet.
	Ordinary Stone ...	48,400 cubic yards.
	Concrete	64,300 cubic yards.
Cement		More than 21,000 tons.
Rivets		6,500,000 (4,200 tons).

Painting. The bridge is painted completely every three years.

Total area of steelwork to be painted ...	145	acres.
Paint used each year	17	tons.
Number of painters employed	29.	

Permanent Way. The two railway tracks are laid on longitudinal oak timbers fixed inside steel troughs. The rails are Forth Bridge Section, 56 feet long, weighing 126 lbs. per yard. They are fastened to the timbers by coach screws. The main expansion joints on the rails are formed by long tongues cut at an angle of 1 in 63, which slide against a backing rail bent at a similar angle. A stepped plate arrangement keeps the running rail always to gauge.

Length— South Approach Viaduct ... ... (4 masonry arches, 10 steel spans)	650	yards.
Main Cantilevers (3)	1 mile 23	yards.
North Approach Viaduct ... ... (3 masonry arches, 5 steel spans)	322	yards.
Total Length	1 mile 1,005	yards.
Heights—Rail Level from High Water Mark ...	158	feet.
Clear Headway for Shipping	150	feet.
Top of Main Cantilever Towers from High Water Mark	361	feet.
Top of Main Cantilever Towers to Lowest Foundation	450	feet.
Workers engaged on construction	4,500.	



THE ROAD BRIDGE

Undoubtedly the great engineering achievement of the Forth Railway Bridge, and its immeasurable importance in communications between north and south since its completion in March 1890, obscured for at least thirty years the need for another bridge across the strait to meet the demands created by the invention and development of the internal combustion engine and the consequent steady growth of road transport.

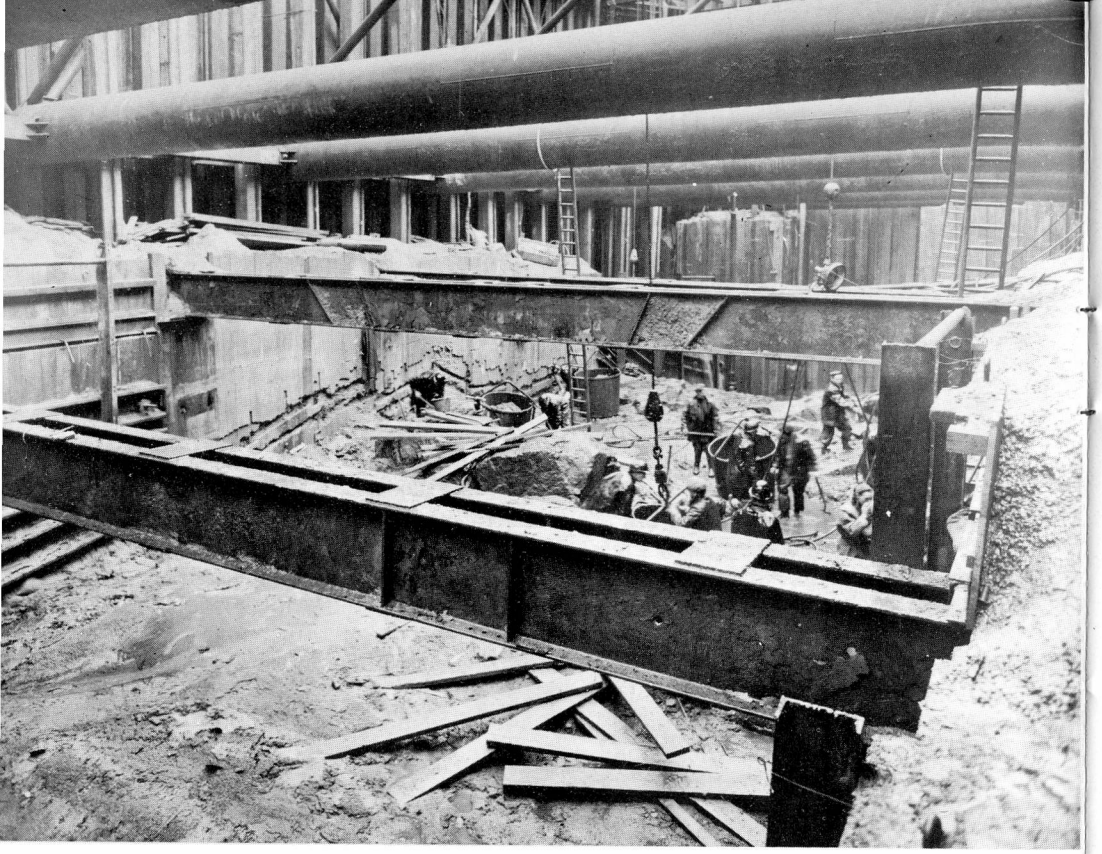
It was in the 1920s that the late James Inglis Ker, a journalist and publicist specialising in road transport and particularly associated with the activities of the Scottish Motor Traction Co. Ltd. (now Scottish Omnibuses), began his campaign for a Forth Road Bridge. He was chief of the Scottish Travel Press and editor of the *S.M.T. Magazine*, now known as *Scotland's Magazine*.

Mr Ker first outlined his proposals for the erection of the Road Bridge at Queensferry to a Press conference at the Hawes Inn, South Queensferry, on November 3, 1923. The meeting was presided over by Bailie W. L. Sleigh, later Sir William Sleigh, of the motoring firm. A subsequent meeting at the Caledonian Hotel, Edinburgh, on January 18, 1924, was attended by members and officials of the Corporations of Edinburgh, Linlithgow, Dunfermline, South and North Queensferry, Inverkeithing, Perth, Kirkcaldy, and Dundee, members of such motoring organisations as the Automobile Association, the Royal Scottish Automobile Club, the Scottish Motor Trade Association, and the Scottish Commercial Motor Users' Association, and representatives of the Scottish Board of Agriculture and the Chambers of Commerce of Edinburgh and Dunfermline. Mr Ker submitted to this meeting the details of the scheme, along with plans and maps.

Sir Henry Maybury, director-general of roads and bridges under the Ministry of Transport, was present and favoured consideration of the proposal. He said that from an engineering point of view no difficulties presented themselves to his mind. On March 25 a Committee of MPs was appointed to urge the scheme on the Ministry of Transport, and on April 25 Mr Henry Gosling, the Minister at that time, stated that he was prepared to defray 75 per cent. of the cost of a survey.

Mr Ker's proposed bridge at that time was a £4,000,000 two-span suspension job passing over the western end of Inchgarvie, the island which supports the central pier of the Railway Bridge. In 1926 the consulting engineers, Mott, Hay & Anderson, were commissioned to make surveys, and various sites were under consideration. In 1931 the present Mackintosh Rock site was selected.

Mr Ker's ideas (he died in September 1936) had just begun to attract some official backing before the worsening of international relations and the claims of rearmament arose as an argument against government



BUILDING THE SUBSTRUCTURE OF THE ROAD BRIDGE

commitment to any such scheme. Mr Hore Belisha, Minister of Transport in 1936, stated that the project did not justify a grant towards the cost, then estimated at £3, 250,000, of which the local authorities were expected to contribute 10 per cent.

By 1939 the scheme had received ministerial approval, but the war held up any development. Discussion was revived when the war ended.

Sir William Darling, one of Edinburgh's distinguished Lord Provosts and an M.P. for one of the city's divisions, proposed that the money for the Bridge should be privately raised.

In 1947 the Forth Road Bridge Joint Board was formed, with representation of the local authorities immediately concerned. Mott, Hay & Anderson were engaged as consulting engineers, and Sir Giles Gilbert Scott as consulting architect. The Government undertook inquiries into the

merits of two proposals apart from that of a new bridge—one for a single carriageway road on a structure carried above the tracks of the Railway Bridge, and the other for a tunnel scheme involving a tube on giant piles above the bed of the Forth.

These ideas were abandoned. In April 1956, Mr James Stuart, then Secretary of State for Scotland, and his Under-Secretary, Mr J. Henderson Stewart, who had expressed interest in the tunnel scheme, announced that a panel of experts had recommended that the Bridge project was most suitable. Once again the Mackintosh Rock site, based on the submerged rock of that name in shallow water west of the Railway Bridge, about 1,200 feet out from the North Queensferry shore, was selected.

To the building of the Bridge the Government agreed to contribute £4,650,000 and the local authorities £500,000, the rest to be found by loans repayable out of toll revenue once the Bridge was opened to road users. The design chosen was a cable suspension bridge with a main span 3,300 feet in length and two side spans each 1,340 feet in length.

THE WORK BEGINS

On January 29, 1957, the Government gave the signal to go ahead on the work, and on December 19 of that year the first advertisements for tenders appeared. These were for the main pier foundations, including compressed air caisson work, and for tunnel anchorages, involving rock tunnelling, and side towers, reinforced concrete.

On June 13, 1958, it was announced that work on the Bridge would start ten days later—on Monday, June 23. The first contract had gone to Farrans Ltd. of Edinburgh for the clearing of sites on both sides of the river. Two squads of workmen, 100 strong, would make a simultaneous start on the demolition of buildings on the two sides. On the south side, at Port Edgar, administration buildings were being demolished and a replacement building erected for the Admiralty, while on the Fife side a large boat store was being erected, the whole operation involving several months work.

The Secretary of State for Scotland (Mr J. S. Maclay) accepted officially on August 25, 1958, the recommendation of the Forth Road Bridge Joint Board for the placing of the first two main contracts for work on the Bridge. These were the contract for the foundations and anchorages (£2,200,000) awarded to John Howard & Co. Ltd. and the contract for the superstructure of the Bridge (£8,660,000), awarded to the A.C.D. Bridge Company.

This A.C.D. Bridge Company was a partnership formed by Sir William Arrol & Co. Ltd., The Cleveland Bridge & Engineering Co. Ltd. and Dorman Long (Bridge & Engineering) Ltd. These companies were

always famous bridge builders, having these among the bridges to their credit :

Arrol.—

Forth Railway Bridge, 1883-90. Cost, £2,000,000. The first big steel cantilever bridge. Two spans of 1,710 feet each.

Tower Bridge, London—one of the earliest bascule spans built.

Benue Bridge, West Africa, 1932. Multi-span steel bridge, 2,500 feet overall, including foundation work.

The new Clifton Bridge.

Cleveland.—

The Howrah Bridge, Calcutta. Cost, £2,500,000. Cantilever bridge, 1,500 feet span. The longest span in Asia and the biggest monolith foundations ever sunk on land.

The Lower Zambesi Bridge, 1934. Cost, £2,000,000. Multi-span steel railway bridge, 2¼ miles long.

The Neath By-Pass, South Wales, and the new Tamar Suspension Bridge of 1,200 feet span.

Dorman Long.—

Sydney Harbour Bridge, 1924-32. Cost £5,000,000. The greatest arch bridge in the world, 50,000 tons of steel, 1,650 feet span.

Storstrom Bridge, Denmark, 1937. Cost, £1,500,000. Longest multi-span bridge in Europe—two miles over water.

Volta River Bridge, Ghana. Cost, £1,000,000. Steel arch of 800 feet span.



Runcorn - Widnes Bridge, Great Britain, 1961.

The new Auckland Harbour Bridge, 1959, was built by the Cleveland Bridge and Dorman Long (Auckland) partnership.

Cost, £5,000,000.

Length, 3,400 feet overall.

At the time of these awards the estimated total cost of the Bridge was £15,000,000.

Already in September 1958, when two joiners and a labourer started on work with the actual Bridge, there were hundreds of applicants for jobs, with the prospect of something like five years' steady employment at high wages. Early in November, work began on the demolition of houses on the north approach road, and on November 21, 1958, Mr Maclay drove in the first pile of the Bridge on the south side, 3½ years after the scheme had been suggested. Lord Provost Ian Johnson Gilbert of Edinburgh, chairman of the Forth Road Bridge Joint Board, also officiated at the ceremony.

Contracts in connection with the Bridge made a long list and were fairly well distributed over the country. For instance, an order for four cranes for the building of the Bridge—special 32-ton cranes for the building of the Bridge towers—was placed that year with the Aberdeen engineering firm of John M. Henderson & Co. and was calculated to ensure a year's full employment for the firm's 600 employees. One of the first jobs on the actual site was the building of a causeway on the north side of the Forth to its terminal point at the Mackintosh Rock, 1,300 feet out—the Mackintosh Rock having been chosen as the spot for the placing of the north end of the Bridge.

In June 1959 two divers blew the top off the 1,800 ton rock for under-water support of the Bridge. They first had to cut up and remove the wreck of a 180-ton barge found lying five feet away. It was believed to have broken away from a North Queensferry shipbuilding yard twelve years before.

Thus work was begun on the substructure of the new Bridge. The north pier was built on the top of the Mackintosh Rock. The south pier was built on caissons sunk through water on to rock. Reinforced concrete towers had to be raised on each bank to carry the shore ends of the two side spans and the end spans of the viaduct, and two massive suspension cable anchorages had to be constructed to take the steel seatings to which the suspension cables are attached.

After this substructure had been completed, work began on the second phase, the erection of the steelwork of the main towers on the north and south piers. Each section of the legs of the towers consisted of three welded high-tensile steel boxes. Each of these was an all-welded assembly made from steel plate up to one and a half inches thick and weighing up to 35 tons. These tower legs were shop-assembled in two stages and were designed to withstand gale force winds, of which there were many before the Bridge got very far in its construction.

While work went ahead on the cable anchorages and foundations, arrangements were being made early in 1960 to haul the central towers from Glasgow to the site.

In May 1960, Mr J. A. K. Hamilton, the resident engineer, who

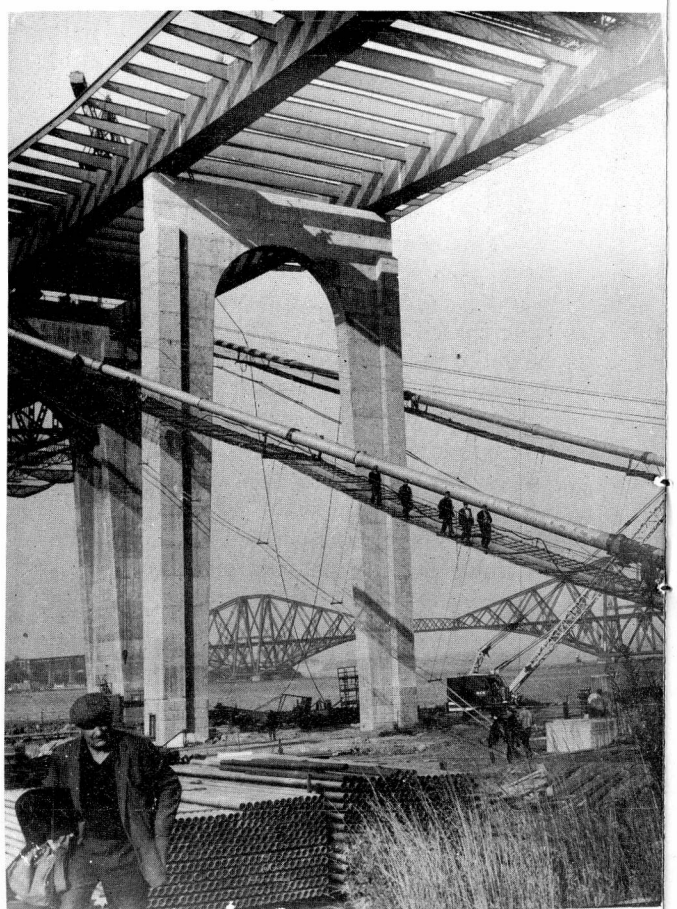
represented the consulting engineers (Mott, Hay & Anderson, in association with Freeman, Fox & Partners), and Mr Hubert Shirley-Smith, agent for the A.C.D. Bridge Company, returned from an American tour which was of importance to the work of construction.

They had been visiting the suspension bridge which was being built at Throgs Neck, New York, between Bronx and Long Island, in order to see work on suspension cables. This was to be the type of work, the first of its kind in Europe, to be used on the construction of the Forth Road Bridge. Mr Hamilton and Mr Shirley-Smith proceeded to set up a school at South Queensferry in which steel erectors were taught the techniques of installing the main cables on their suspension bridge.

An Edinburgh firm—A. M. Carmichael, civil engineering contractors, Ainslie Place—were awarded in June 1960 the £800,000 contract for the construction of the 3½ miles southern approach road. It would employ something like 300 men at peak.

TOWERS AND CATWALKS

Soon the 512 feet towers of the Bridge became conspicuous features of the river-scape, seen to particular advantage from the Railway Bridge. On November 30, 1960, Lord Craigton, Minister of State, made a headline story when he was trapped for an hour in an open lift 180 feet up in the north tower in the course of an inspection tour in a 50 mile an hour gale. Difficulties with the strong winds in the Forth were to be a frequent feature of the work on the Bridge, and were to cause considerable delays before the work was completed.



Before the end of 1960 contracts worth a total of more than £3,000,000 were awarded for work on approaches to the Bridge. They were to Watlings Ltd., Glasgow—£2,250,000 for work on the northern approaches —and to Reed & Mallik Ltd., Muir of Ord, Ross-shire—£920,000 to build viaducts, including piers, superstructure and roadway on the northern approaches.

The first link between the north and south towers was established on July 5, 1961, when a cable 6,000 feet long and one inch thick was stretched across the Forth, the first of 22 wire ropes to support two temporary catwalks. These catwalks, linked together by seven cross bridges, were to be used in spinning the main cables. About ten feet above each catwalk an endless hauling rope was hung, and men were posted at intervals of 150 feet along the catwalks.

THE NAVY LARK

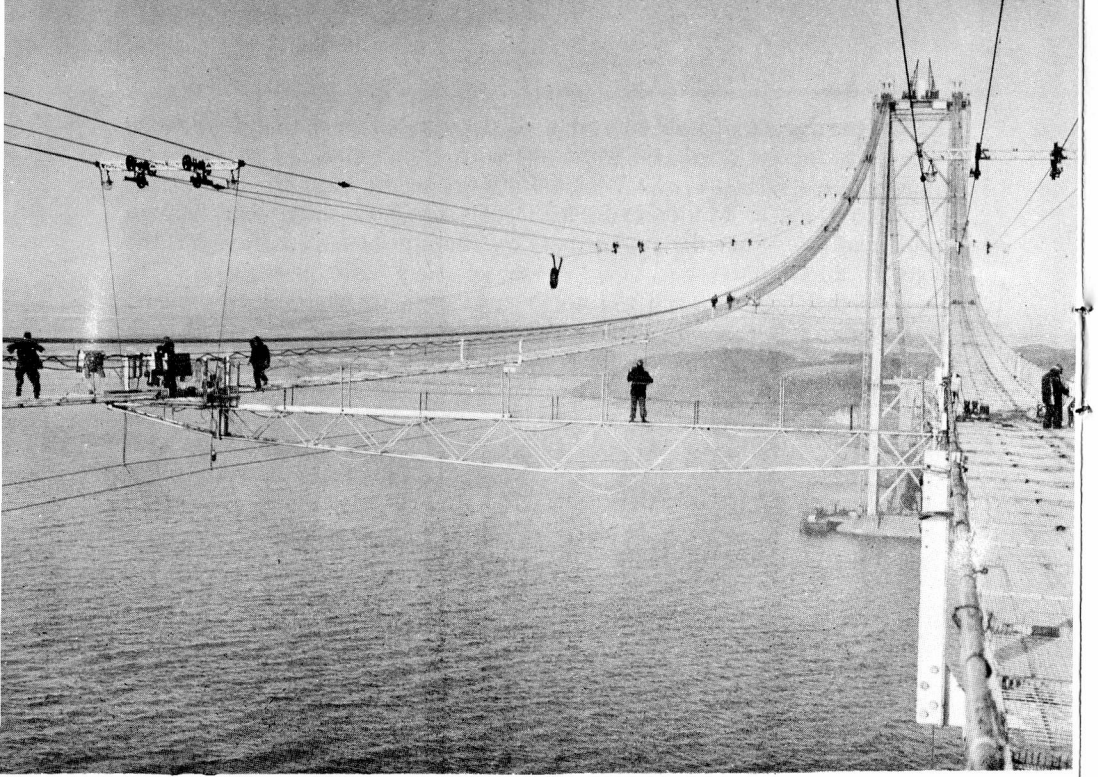
In August, with the cables to support it in position, the first catwalk was moved into place and tested. In September 1961 James Laverty, senior foreman, became the first man to cross the Forth on the 3,000 ft. catwalk, 9 ft. wide, 500 ft. above the water.

A month later came the first unauthorised crossing. Tom Hess, a 27-year-old Liverpool Navyman, from the frigate *Russell* lying at Rosyth, missed his boat home from the south side and took it into his head to walk across 300 feet above the water. It took him 2 hours 20 minutes in the middle of the night and led to Sheriff V. D. B. Skae's imposition of a fine of £10 at Linlithgow Sheriff Court. A Kirkcaldy business man, who admired the historic feat, paid £2 of the sailor's fine. Another seaman, William Moran, a 20-year-old steward, who pleaded guilty by letter to breach of the peace but had turned back from his attempt on the bridge when cautioned, was fined £5.

The catwalk seemed to be a challenge to the Navy, though two extra watchmen were put on duty to keep sailors off. Several more sailors committed the offence and were fined £3 in each case, before Vice-Admiral R. H. Wright, Flag Officer, Scotland, sent a message to all local ship and shore establishments—" Stay off the Bridge ! "

SPINNING THE CABLES

Cable spinning, which was started on November 17, 1961, and completed on August 7, 1962, after many delays caused by adverse weather conditions, was the method used to form the two steel wire cables passing over the 512 feet towers and securely anchored in the



CATWALKS, TRAVERSE BRIDGES, TRAVELLING CABLES

rock at the north and south shores, to bear the weight of the deck of the Bridge and its burden of road traffic. These cables are over two feet in diameter. They had to be manufactured in place, wire after wire being drawn across the river between the towers and laid in careful parallel formation so that each wire takes its share of the total load.

The wires of which these cables are made up are about one-fifth of an inch in diameter. They were not twisted together but were laid parallel to one another. They form strands grouping 314 wires. Thirty-seven of these strands, held together in hexagonal formation, make up each cable. When the spinning was complete the cables were reduced to circular shape by a compacting machine which was slowly traversed throughout the length, applying lateral pressure by a battery of hydraulic jacks mounted in a circular formation. Later the cables, after receiving anti-corrosion treatment, were given a continuous binding of soft galvanised steel wire.

This is known as Roebling's method of cable construction. It was first used in 1845 on the Pittsburgh Canal. The Forth Road Bridge is the first example of its use in Europe.

It was in order to carry out this intricate and difficult operation that the catwalks and handrails were placed in position, with overhead an endless rope haulage arranged so that a free-running pulley block could be carried backwards and forwards from shore to shore.

From drums mounted on the south shore, the wires for the suspension cable were first passed through a tension-equalising device. They were looped over the sheaves of the travelling pulley block and also firmly fixed to strand shoes in the south anchorage.

The pulley block was then traversed across the river, laying two wires along the catwalk for every sheave in the block and carrying the loops to strand shoes in the north anchorage. Relieved of its load, the pulley block was returned to the south shore, where again wires between the cable drums and the southern anchorage strand shoes were looped over the sheaves and carried across the river. This process was repeated until 314 wires hung between the anchorages. These wires were then grouped as one strand and placed in position in spacing frames fitted in the catwalk.

Other strands were built up in the same way. Eventually 37 strands lay in the frames, spaced in hexagonal arrangement. The parallel laying of the wires facilitated the next process, that of compacting the cable from the hexagonal shape to a tight circular form. The grouped strands were no longer identified but had served the purpose of ensuring an even distribution of stress throughout 11,618 individual wires.

Thereafter the cable was treated to prevent corrosion before being bound with a soft galvanised wire. These two suspension cables were wound on the site with high-tensile wire drawn from metal with a breaking strain of 110 tons per square inch and 0·2 per cent. proof stress of 75 tons (that is to say, to produce a 0·2 per cent. permanent elongation requires a load of 75 tons per square inch). The wire —one-fifth in diameter (area 0·0302 square inch)—is heavily galvanised to resist corrosion. Over 30,000 miles of wire were required to complete the two cables. They were joined by steel tubes subjected to a 120-ton squeeze in a hydraulic press.

THE ROEBLING SYSTEM

Cables of parallel wire made in this way were invented over a hundred years ago by John A. Roebling. They were used in the Brooklyn Bridge in 1883, and their use became standard practice in the building of bridges of great span in the United States, where they had all the specialised and costly plant required.

In order to construct these cables for the first time in Europe the builders of the Forth Road Bridge consulted Roeblings of Trenton, U.S.A.

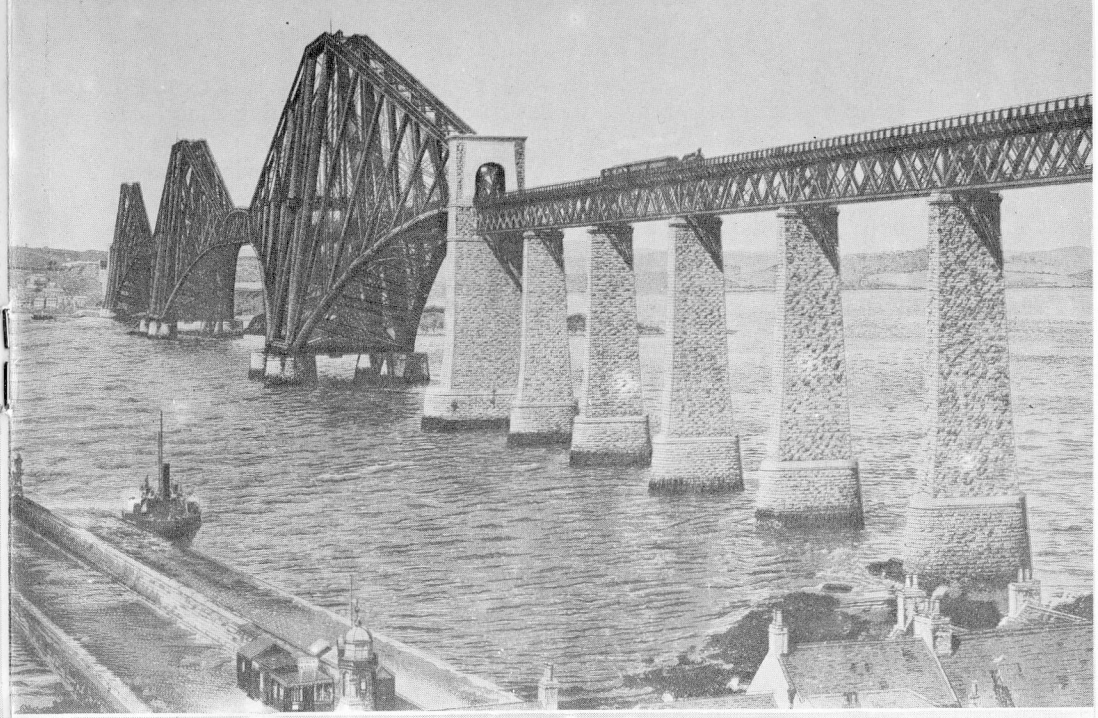
Spanning the Forth

THE RAILWAY BRIDGE

Opened by the Prince of Wales — later King Edward VII — March 4th 1890

THE ROAD BRIDGE

Opened by H.M. Queen Elizabeth II — September 4th 1964





They gave great assistance in the design of the cable spinning equipment and the organisation set up at the Forth Road Bridge site.

In the Forth Road Bridge cables the 30,000 miles of wire required were enough to stretch 1¼ times round the world. The entire 6,350 tons of wire were made by Dorman Long (Steel) Ltd., and 1,500 tons were immediately delivered to the site in 10-cwt coils. The balance was stored under cover in Middlesbrough in big polythene bags.

In the reeling shop at the south end of the Bridge site the coils of wire were loaded on to swifts by the pillar cranes and reeled through the tension devices on to the ninety drums, each capable of taking 7 tons of wire. The loaded drums were mounted in turn on eight unreeling machines set up behind the south anchorage, to deliver the wires through the counterweight tower to equalise the tension and on to the spinning wheels to carry them over the span.

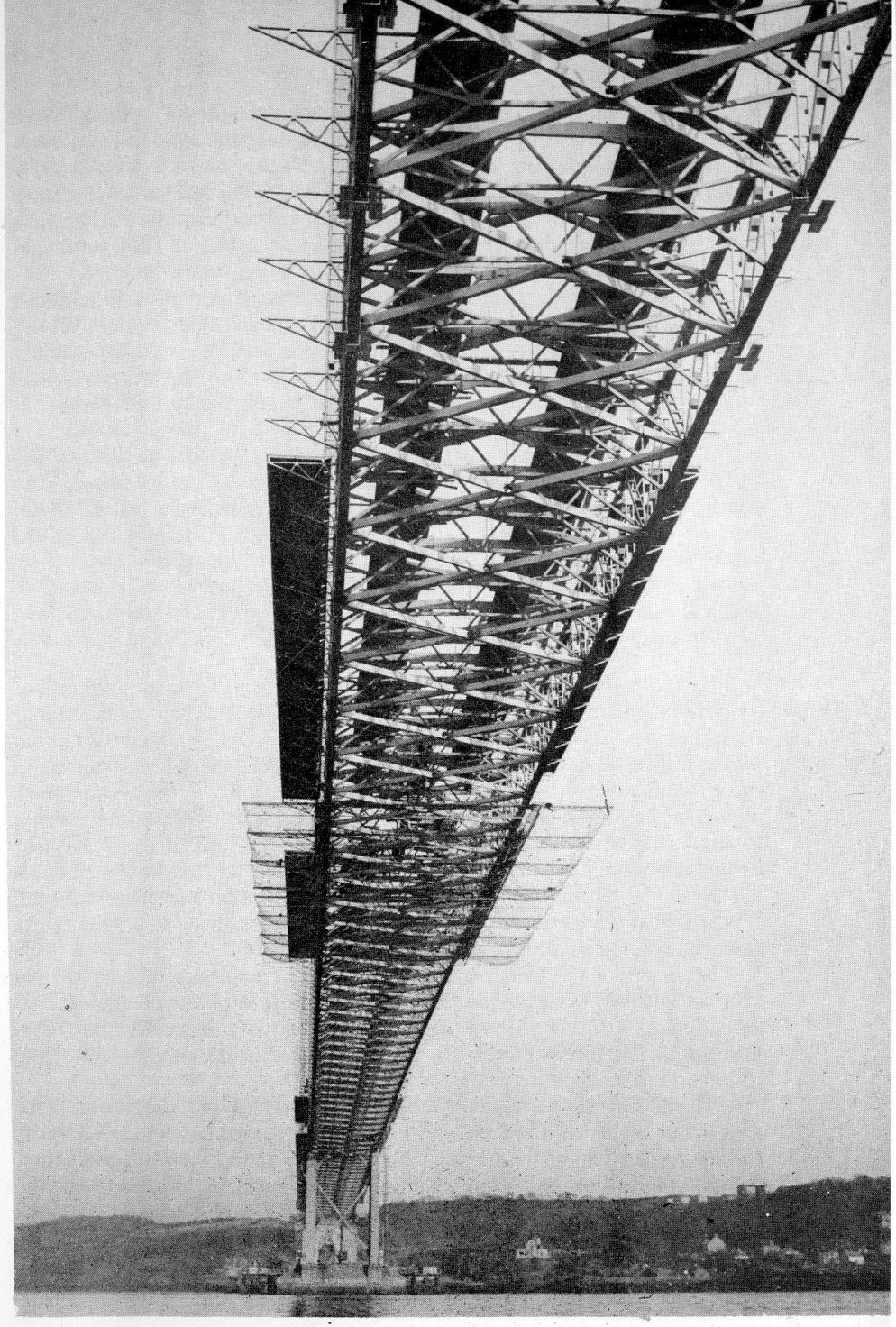
While the spinning was in progress the lights installed the length of the catwalk and blazing through the night made a fine sight festooned across the river. Phone lines were laid along the walks and electric code signals and come-alongs assembled for use in adjustment of the wires. Fifty or sixty men worked on the 6,000 feet of catwalk at heights up to 500 feet above the water, for eight-hour shifts without a break, except when winds were so strong that they made the work impossible.

When cable-spinning was finished on August 7, 1962, the bridge was two-thirds on its way to completion. The occasion was celebrated with a wheeled trolley decorated with flags and a length of Ross tartan, the latter in memory of Mr David Ross, a senior engineer who had died of a heart attack as the work was nearing its end. The operation had taken eight months—three more than had been expected. This was because of the bad weather, and particularly the high winds which had caused repeated postponements. The next phase—the compacting of the strands—now began, and was completed in about three weeks.

THE DECK

Earlier in the year—May 8, 1962—a start was made on the building of the deck section. About sixty feet of the structure on either side of the two main towers was put into place, preparatory to the suspension of the remainder of the deck from the cables.

The steelwork for the decks was delivered by road to the foot of the main towers. It was then raised to deck level and erected by electric derricks. These travelled out from the towers, placing the steel structure in front of them as they went. Thus the deck grew out in both directions from the towers to meet in the middle of the span.



That August there was another version of " The Navy Lark "—an American Navy helicopter pilot, Lieutenant Donald Calder from New Jersey, with his co-pilot, Lieutenant Charles Gates, and three other crew members, became the first to fly a machine under the 300 feet high centre cables. The plane was from the 6,000 ton depot ship U.S.S. *Tanner*, which was then at Rosyth on a hydrographic cruise. The comments of the men working on the bridge were said to be unprintable.

On June 5, 1963, there was a similar sensation when the Stockholm millionaire, Sigurd Hallstrom, President of the Swedish Water Ski-ing Federation, flew under the bridge at night in thick fog, with Mr Anders Sotherson and Mr George Wilkins as passengers. They were on their way to water ski championships and pleaded that they had wandered off course.

The third stage of construction was begun on October 31, 1962, when the first of the suspenders from which the road would hang was put in place depending from the cable. There are about 200 of these, ranging in length from 200 feet near the towers to 20 feet at the centre of the span.

BRIDGING THE GAP

By the end of 1963 the Bridge was beginning to look something like its ultimate picture. In November, Mr Robert Wilson, a constructional engineer, was appointed its first bridgemaster. On December 20 came the joining of the two sides of the Bridge deck which had gradually grown out across the Forth from south and north. The spans were joined in the middle at a special ceremony. By a triumph of engineering it was found that the gap left to take the final section of the 3,300 feet Bridge was within an inch of what was calculated on the drawing board. Mr J. A. K. Hamilton, the resident engineer, was quoted as saying: " When two ends of a bridge meet, it is certainly very satisfying. Sometimes they don't."

Members of the Forth Road Bridge Joint Board and representatives of neighbouring local authorities took part in the joining ceremony, 200 feet above the waters of the Forth. Lord Provost Duncan Weatherstone, Edinburgh, chairman of the Board, signalled the bridging by the firing of a Verey pistol.

The linking up of the spans which had thrust their way out from towers five-eights of a mile apart took a little over an hour. Union Jack, Lion Rampant, and St Andrew's Cross flags fluttered from the structure. Steadily, with keen precision, the spans were handled into position, the squads working by signal as they nursed the 10 ton, 60 foot sections into the gap.

By this time the total number of men employed on the Bridge had reached 450, in contrast to 4,500 employed on the Railway Bridge. The cost of the Bridge, excluding the approach roads, had risen to an estimate of £11,500,000, with the roads bringing it up to anything between £16,000,000 and £20,000,000.

In June 1964 they were taking down the catwalks.

There were still 130 steel erectors at work and a further 130 men engaged on the road surfacing of the Bridge. Already we had, in existence, a wonder of engineering—29,500 tons of steel in the towers, deck and cables. The 3,300 feet main span made it so far the world's fourth largest suspension bridge, though soon the Narrows suspension bridge in New York would push it into fifth place for length.

Its neighbour, the Forth Railway Bridge, had held its world's record for cantilever span for 28 years with its two main spans of 1,700 feet thrust out from the massive steel towers. Then the Quebec Bridge over the St Lawrence had taken over first place, with a span length of 1,800 feet.

There was pleasure in Scotland when it was announced that 3d and 6d stamps would be issued to commemorate the opening of the Bridge, and there was even greater pleasure when it was learned, a month before the ceremony, that the Queen herself would declare the Bridge open.

FATALITIES

There have been accidents and injuries, and three fatalities in the actual building of the Bridge. (There were 57 lives lost on the erection of the Railway Bridge.)

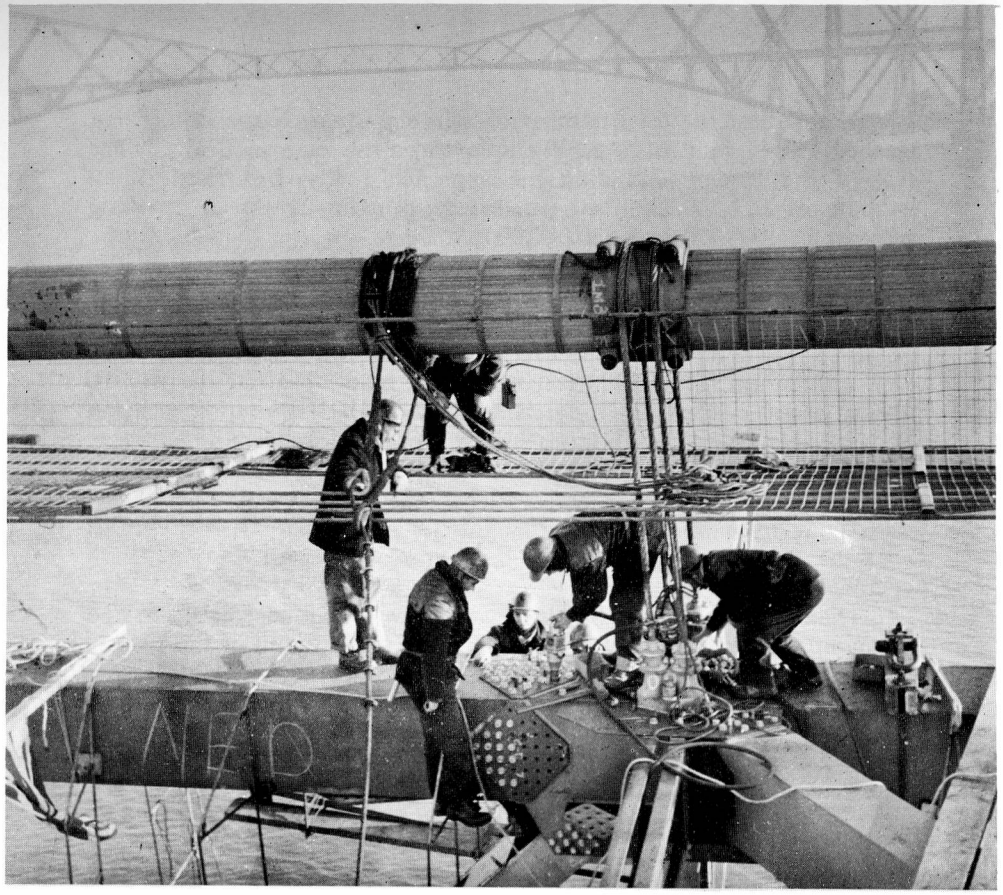
When Kevin Munelly was killed by flying metal 500 feet up on the Road Bridge south tower on March 12, 1962, his workmates spontaneously subscribed £2,000 for his widow.

In June 1962 three Fife men died in the collapse of a fly-over at Masterton on the northern approach road, the accident having been caused by ground movement.

When it seemed as if the Road Bridge had escaped with one fatality, one was killed, one was missing, and two were injured in an accident on July 10, 1964.

This accident occurred when the men were at work moving a safety net, which, along with safety belts, safety boots and crash helmets, figured among the precautions used throughout operations.

Even in the early stages of construction, despite these measures, there were mishaps. In November 1959 a man was crushed by a hutch at the workings in South Queensferry. A chainman broke his spine when he fell from a cofferdam.



BRIDGING THE GAP UNDER THE BIG CABLE

On the Bridge itself high winds were a problem. In February 1961 they threatened the safety of six men who were being lowered in a bucket from the north main tower, 480 feet up. That same month there was an explosion 135 feet underground in the workings of the Bridge, where fire damp was suspected as the cause, and five men were injured.

In December a man working 600 feet above the water slipped in his frost-covered boots on the catwalk struts and tumbled several yards down the steel-mesh footbridge. He was saved by his crash helmet as he hit the temporary deck. Two were injured by the accident which killed Kevin Munelly, when a winch lowering a 4-ton staging suddenly disintegrated. Here again the safety precautions proved their value.

In September 1962 two men working on the Bridge, dismantling the wire-spinning wheel in the middle of the span, were injured when a ladder slipped on a three-feet-wide catwalk 150 feet above the water.

Safety nets made of nylon helped to save lives. They broke the fall of Danny Slattery when he dropped 60 feet into one of them and then dived 120 feet into the Forth. He had a narrow escape, and his misadventure led to extensive tests on the nets with sacks loaded with 220 lbs. of nuts, bolts and wet sawdust. The following month, in May 1963, a charge-hand on the cable spinning plunged 45 feet from the Bridge into a net 100 feet above the water. They said he bounced like a trampoline artist, but the net held. He sustained a broken thigh. A doctor who rushed two miles to the Bridge from Inverkeithing was lowered in a bucket to attend to him where he lay.

Despite the dangers, which were naturally not courted by the workers on the Bridge, there were some outsiders foolhardy enough to tempt Providence. In addition to the catwalk sailors and the history-making airmen, there were those eternal clowns, the students. On April 23, 1962, a banner 30 feet long, publicising Edinburgh University students' charities, appeared on the top of the south tower. It had involved a 500 feet climb at night, either by workman's ladder or by catwalk from the shore.

Industrial disputes played a minor part in delays—a three-week strike of welders who were fabricating the steel sections for the Bridge, a soon solved dispute of 26 joiners over the length of their tea-break, a slight stoppage over bad-weather payments, some brief stoppages among the steel erectors over an argument about bonus payments. Weather conditions, which played their part also in the creation of this grievance, were the commonest factor in the hold-ups. They were so bad in the course of the cable-spinning operation, according to Mr H. Shirley-Smith, that 33 per cent. of spinning time was lost. Spinning was impossible in winds of more than 30 miles an hour. The Firth of Forth has plenty of these, in contrast with the conditions on the building of modern American bridges, on which not more than 5 per cent. of spinning time was lost.

The following facts and figures about the Forth Road Bridge were kindly provided by the consulting engineers :

DIMENSIONS

Centre span	3,300 ft. long.
Side spans	1,340 ft. each.
Southern approach viaduct (11 spans) ...	1,437 ft.
Northern approach viaduct (6 spans) ...	842 ft.
Total length, from south abutment to north abutment	Over 1½ miles.

The main bridge is composed of :

Cable Anchorages. There are four anchorages. They differ in design on the north and south sides. They consist of tunnels driven into the rock at 30 degrees and at 78 feet centres. On the north side the tunnels are 19 feet by 25 feet at the portal and tapering to 40 feet square at the base in a length of 175 feet. The south side tunnels are 25 feet in diameter at the portal, extending for 170 feet at this diameter and then increasing to 35 feet for a 15 feet length and to 45 feet diameter for the final 40 feet of length. Each tunnel is filled with about 10,500 tons of low heat concrete. Through this 114 steel tubes of 4½ inch diameter are placed for carrying stressing cables which retain 19 steel crosshead slabs at the anchorage faces. The crossheads carry two strand shoes each. Around these pass the wires forming the main cables.



Side Towers. The reinforced concrete side towers support the inshore end of the side span stiffening trusses and the riverward ends of the approach viaduct spans. They also carry steel saddles. These deflect the main cables downwards towards the anchorages. They are founded at approximately minus 10 O.D. The towers are 150 feet high. They consist of twin shafts joined by arched ribs 120 feet above ground level. The legs are 32 feet by 20 feet in section, with walls 2 feet thick at the base.

Main Piers. The North Pier is founded on a submerged reef known as the Mackintosh Rock, which varied in level from 12 feet to 26 feet below water. The concrete pier is founded on whinstone at minus 30 O.D. and was formed of mass and reinforced concrete inside a steel sheet piled cofferdam.

The South Pier is founded on sandstone at minus 95 O.D. or 87 feet below low water. It was built by sinking two 60 feet diameter caissons in free air inside a steel piled cofferdam. The piling of this was driven some 10 feet into the boulder clay overlying the rock. The cylinders were united by a heavy reinforced capping beam upon which the rectangular pier with cutwater ends was built.

Main Towers. These are both 512 feet high. They are welded of high tensile steel and they provide the main supports of the cables. Each tower leg consists of 33 welded box sections, machined at their ends, and 44 cover plates. Connections at site are by high tensile screwed rods and close tolerance bolts. The diagonal bracing is of welded box construction with grip bolt connections.

Cables and Hangers. The cables have a compacted diameter of 24 inches and each is composed of about 12,000 wires, ·196 inch diameter of high tensile (100-110 ton) galvanised steel, laid parallel.

For the purpose of cable erection, temporary footwalks consisting of wire mesh panels supported on wire ropes were provided just below the cable profile. An endless tramway rope above the footwalk carried the spinning wheel which hauled 4 loops of wire at a time across the river. The wires were then adjusted for sag and made up into 37 strands of about 300 wires each.

Cast steel cable bands at approximately 60 feet centres support the hanger ropes on the main cable. Each hanger consists of two loops of wire rope, $2\frac{1}{4}$ inch diameter, in the side spans, and $1\frac{7}{8}$ inch diameter in the main spans, which have been cut to length and socketed by the makers.

Stiffening Truss. The truss consists of two lattice girders 27 feet 6 inches, made of welded box cords and battened channel posts and diagonals. Cross girders at 30 feet centres support the deck. This is

of stiffened steel plate construction in the main span and reinforced concrete in the side spans. It has asphalt surfacing. The deck provides two 24 feet roadways, two 9 feet cycle tracks and two 6 feet footpaths.

Approach Viaducts. Concrete abutments mark the ends of the approach roads and two viaducts connect them with the suspended structure. Reinforced concrete piers at intervals of 110 to 177 feet support the deck structure. This is of steel box beams carrying cross girders working in composite action with a reinforced concrete slab.

Protective Treatment of Steel. All external steelwork surfaces are given the following treatment :

1. Shot blast to remove all rust, scale, etc.
2. Sprayed coating of metallic zinc, ·003 inch thick.
3. One coat of etch primer.
4. One coat of zinc chromate primer.
5. Two coats of " Ferrodor " finishing coat.

Quantities. The approximate quantities of steel in the various parts of the bridge are:

Towers	6,000 tons.
Cables	8,000 tons.
Suspended Deck	16,000 tons.
Reinforcement in concrete ...	6,000 tons.
Miscellaneous	3,000 tons.
Total	39,000 tons.

Southern Approach Roads. The approach road extends from the viaduct abutment for 3 miles to join the A.90 at Dolphington. From this point the A.90 was reconstructed a little beyond the Edinburgh City Boundary at Cramond Bridge.

A two-span flyover at Dolphington carries Edinburgh-Queensferry traffic over the approach road. Single and four span bridges at Dalmeny carry the approach over a minor road and the main Edinburgh and Glasgow to Aberdeen railways. Scotstoun Bridge carries Kirkliston traffic on to the interchange junction at Echline, where Bo'ness and Queensferry traffic also join the approach. All bridges are of reinforced concrete construction with the exception of Dolphington Overpass which is carried on welded steel box beams.

East of Dalmeny, the approach cuts into the foot of a bing of burnt shale residue. This has meant the removal of three-quarters of a million cubic yards of material which has been used to form road abutments

and sub-base. Carriageway construction is 6 inches of stabilised shale residue, 8 inches of lean mix concrete and 4½ inches of asphalt. Two 24 feet carriageways are provided with 18 feet-6 inch verges and a 10 feet central reservation.

Northern Approach Roads. This approach carries traffic from the Bridge to the A.90 about 1½ miles north of Inverkeithing. Three interchange junctions are provided—at Ferry Toll for North Queensferry and Inverkeithing, Admiralty Road for Rosyth and Kirkcaldy, and Masterton for Dunfermline and subsequent connection with the East Fife Regional Road.

Two deep cuttings form the most prominent features. The first is through whinstone at St Margaret's Head. From this place a million cubic yards of material were removed. The second is at Castlandhill—an 80 feet deep clay cutting. Rapid variations in topography and geography in the area entailed large earthworks in material varying from rock to peat and soft clay. A large area of clay south of Masterton was crossed by using a piled raft and an 800 feet viaduct. The scheme involved the construction of 12 reinforced concrete bridges in addition to the viaduct.

Cost. The estimated cost of the complete scheme—£18,000,000.

TOLL CONTROVERSY

The Provisional Order for the Forth Road Bridge, lodged with the Government in March 1946, provided for tolls as a means of recovering the expenditure of local authorities on such a project. An Edinburgh business man, Mr Leonard Bailey, told the Chamber of Commerce in November 1954 that the toll system, which was the method of financing roadways in the United States, should be applied to the Forth Road Bridge : " It is no use asking for roads to be built unless the funds are there."

Tolls were built into the scheme as announced in November 1956, whereby the Government promised £4,650,000 towards the cost of the Bridge. This was almost one-third of the total cost then estimated at £14,250,000. Tolls would be charged to repay loans advanced to the Forth Road Bridge Joint Board by the Government. The constituent authorities of the Board were to contribute £500,000.

As Mr J. Kenneth Anderson, of Mott, Hay & Anderson, told the Edinburgh and East of Scotland Association of the Institution of Civil Engineering in December 1954, the estimated cost of the Bridge had risen from £4,500,000 before the war.

An organisation called the National Forth Road Bridge Committee, which existed to speed up the building of the Bridge, expressed its

opposition to the idea of tolls through its convener Mr Nigel Tranter, the well-known Scottish novelist. This protest admitted that in 1946 the contributing local authorities had agreed to the imposition of tolls, but claimed that the conditions of that period no longer applied. Now the Government was taking £700,000,000 in licences and taxation from road users and not spending a seventh of it on the roads.

The Committee urged that the Joint Board, all other local authorities, municipal candidates, and motoring, trade and other representative organisations, should take up the matter forthwith. Meanwhile the Committee made representations to the Secretary of State for Scotland.

Support soon came from the Scottish Licensed Trade Association, which made its protest against tolls to the Joint Board.

Mr Maclay, the Secretary of State, replied on July 3, 1961, that it was the Government's policy, in projects where an additional convenience was given to road users, that the road users should make a payment for it. This applied particularly to river crossings. Each project was costly, and there were other urgent demands on the funds available for road improvements.

Later that month the Scottish Division of the Traders Road Transport Association argued that there was no justification for the toll, and that the Bridge, as part of the highway, ought to be financed out of motor taxation.

In November that year the Forth Road Bridge Joint Board instructed Mott, Hay & Anderson and Freeman, Fox & Partners to prepare a report on the volume and make-up of traffic likely to use the Bridge, and on suggested rates of toll and methods of collecting the toll.

Opposition was strong from members of the local authorities, and from local M.P.s, with several organisations such as the Scottish Auto Cycle Union and the Melville Motor Club joining in, and at least one garage owner collecting signatures of protesters.

Lord Provost J. Greig Dunbar, however, told the Ecurie Ecosse Association at their dinner in February 1962 : " The local authorities concerned agreed that there should be tolls.

" It was on this basis and this distinct understanding that we were allowed to proceed.

" For any local authority to support objections is, in my view, quite wrong and a clear breach of faith."

A plea by the M.P. for Dunfermline, Dr Alan Thompson, against the tolls was turned down by Mr Maclay in these terms : " Government assistance offered to and accepted by the Joint Board in 1956 was based on tolls." The Secretary of State by this time had received thirteen representations against tolls, mostly from Fife.

The Town Clerk of Dunfermline, Mr John Douglas, looking into

the question for the benefit of his council, found that in 1947, at a time when the Government had no interest in levying tolls the constituent councils had decided that tolls should be levied. They sought and obtained Parliamentary powers for this. They did the same in 1956 and again obtained powers.

There were still further protests by town councillors and in Parliament, but Lord Provost Dunbar told Edinburgh Town Council, " We cannot break a bargain."

In August 1963 the Joint Board decided to recommend a flat rate toll of 2s. 6d. for each vehicle. Lord Provost Duncan M. Weatherstone of Edinburgh thought this was not enough to meet the purpose and suggested 4s. The Government's Scottish Development Department also thought the 2s. 6d. toll too low, but on March 26, 1964, Mr Michael Noble, Secretary of State, gave his decision in favour of the 2s. 6d. toll for the first year of operation at least. It was calculated that this would mean a crossing of 5,000,000 vehicles a year, and 17,000 a day in summer.

Despite the protests, the half-crown flat rate was welcomed by most road users habituated to paying to cross by ferry on the Queensferry Passage, where the rates were, for small cars up to 1,000 c.c., 4s. 6d. ; for 1,001 to 1,700 c.c., 5s.3d. ; for 1,701 to 2,500 c.c., 7s. 3d., and for upwards of 3,000 c.c., 8s. 3d.

One of the chief opponents of tolls, Mr John McWilliam, a Fife councillor who was vice-convener of the Joint Board, nevertheless led a deputation on an 8,000-mile trip to see methods of toll collection. They investigated the working of machinery at George Washington and Throgs Neck Bridges, Lincoln and Battery Tunnels, and Triborough Bridge and Tunnel, and also visited Buffalo and Montreal.

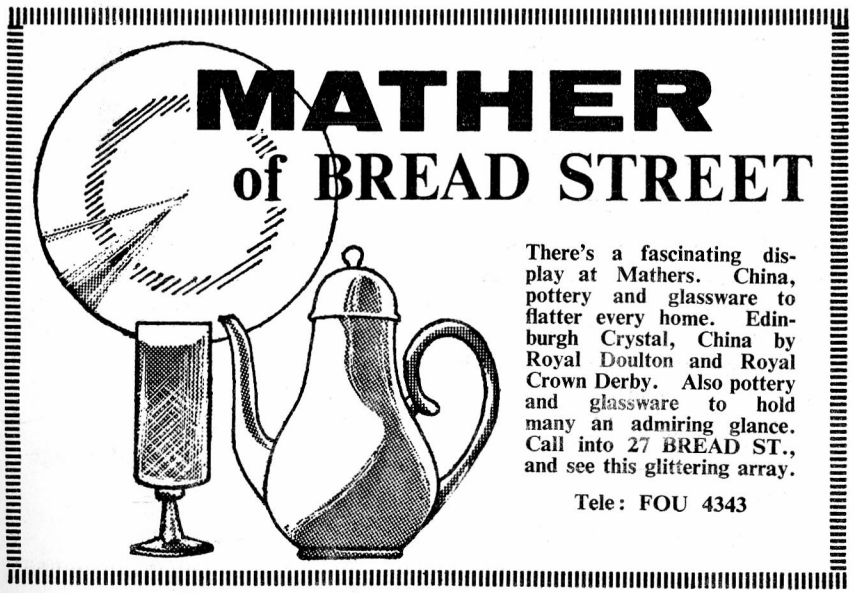
It was agreed to introduce automatic tolls at the beginning on two of the Forth Road Bridge's eight lanes, and gradually to change over completely to the automatic system as the public became used to it.

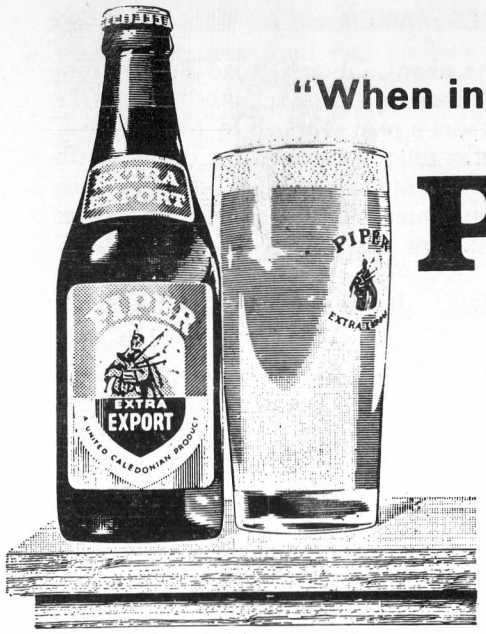
In December 1961 it was stated that arrangements were to be made to absorb the 74 ferrymen—masters, mates, deckhands and piermen—operating the four ferry boats for William Denny & Sons, Dunbarton, into the operation of the Forth Road Bridge.

DISTANCES SAVED

Early in the campaign to bring about a Forth Road Bridge from South Queensferry to Dunfermline Road by the Mackintosh Rock (the proposal prepared by J. Inglis Ker from a plan supplied by Mott, Hay & Anderson) comparisons were made as follows between the distances (in miles) from Edinburgh to the North by Stirling (the land crossing then available) and by Queensferry. I have interpolated the relative distances by the Kincardine-on-Forth Bridge which was provided in the interval :

Edinburgh to	By Stirling	By Kincardine	By Queensferry
Dunfermline ...	57½	38	15
Kirkcaldy	70¾	51	23½
St Andrews ...	86½	78	50½
Perth	70	64	42
Dundee	91	86	51
Aberdeen	153	147	124
Inverness	184	180	156





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ACKNOWLEDGMENTS

The author wishes to acknowledge generous guidance and co-operation from the following :

The Press and Public Relations Department of British Railways, Scottish Region ;

The Resident Engineer's Department at the Forth Road Bridge, and the Agent of the A.C.D. Bridge Company ;

And, for permission to reproduce photographs ;

British Railways ;

Mott, Hay & Anderson, Consulting Engineers, Forth Road Bridge ;

The Scotsman ;

Glasgow Herald.

The photographers for Mott, Hay & Anderson were W. Ralston Ltd., Glasgow.

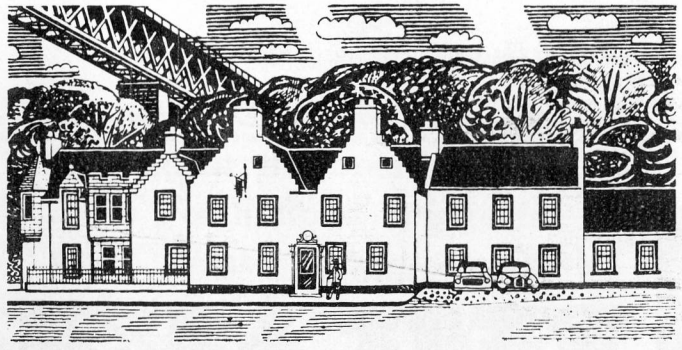
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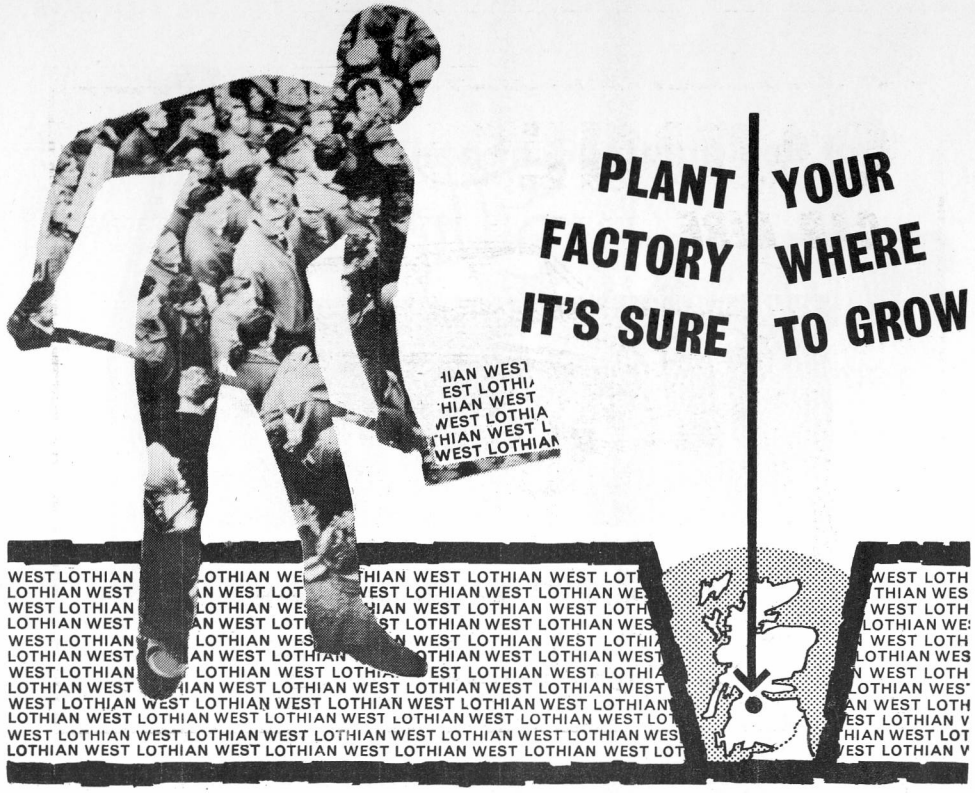
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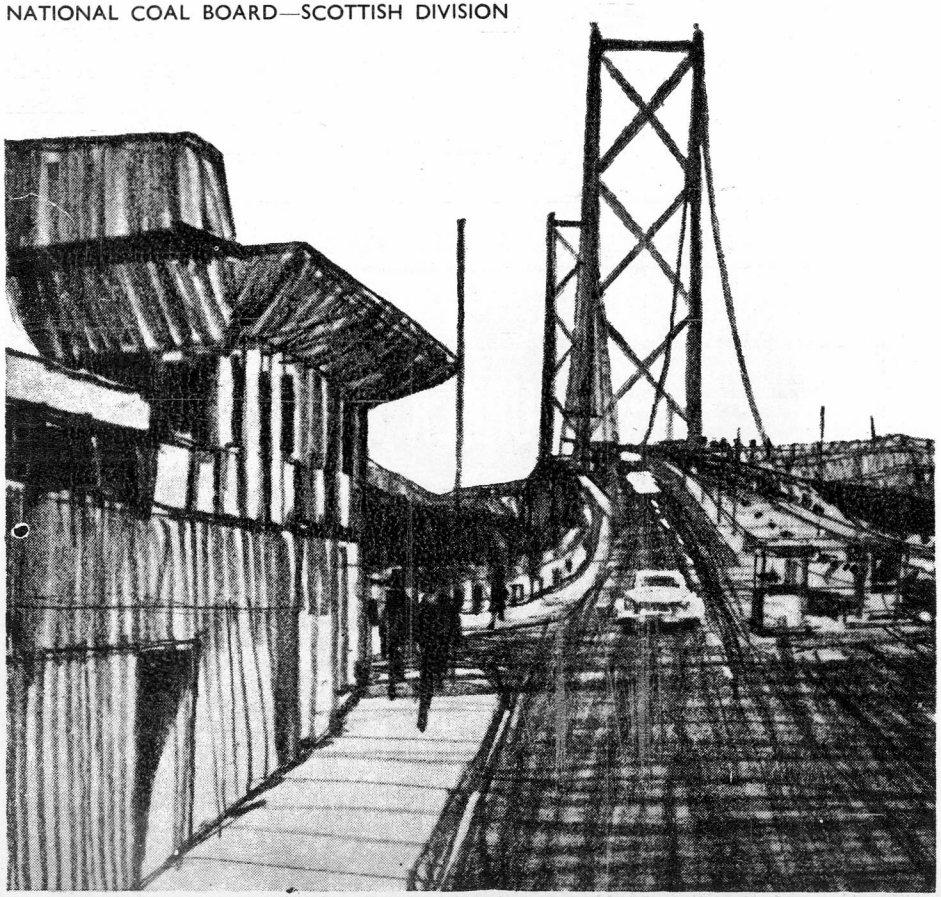
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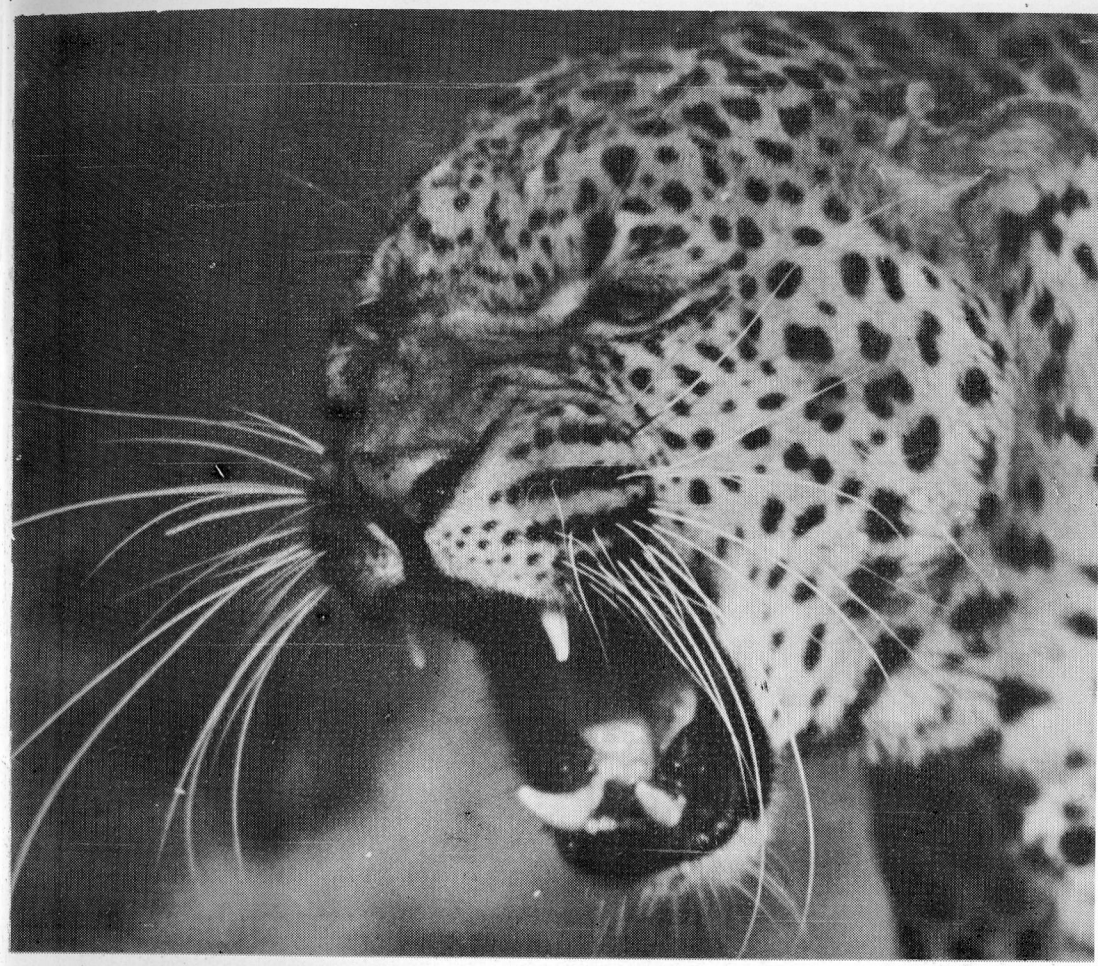
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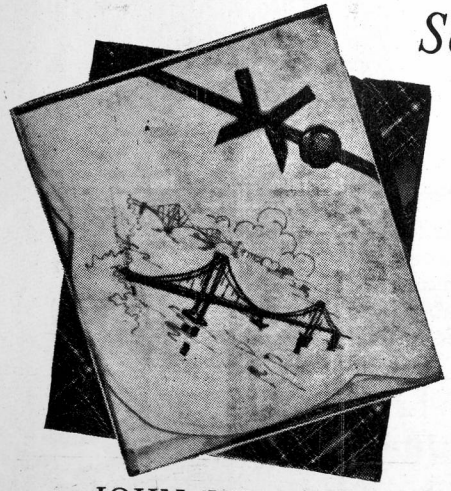
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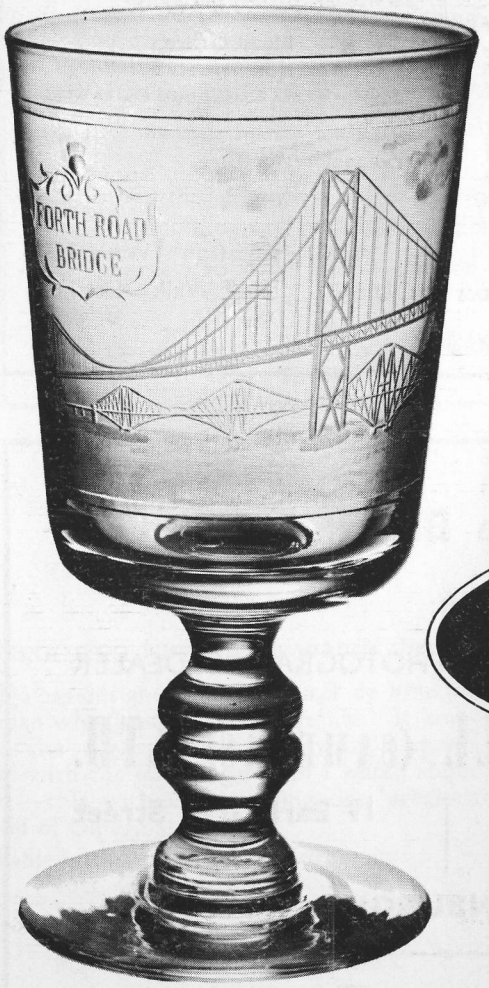
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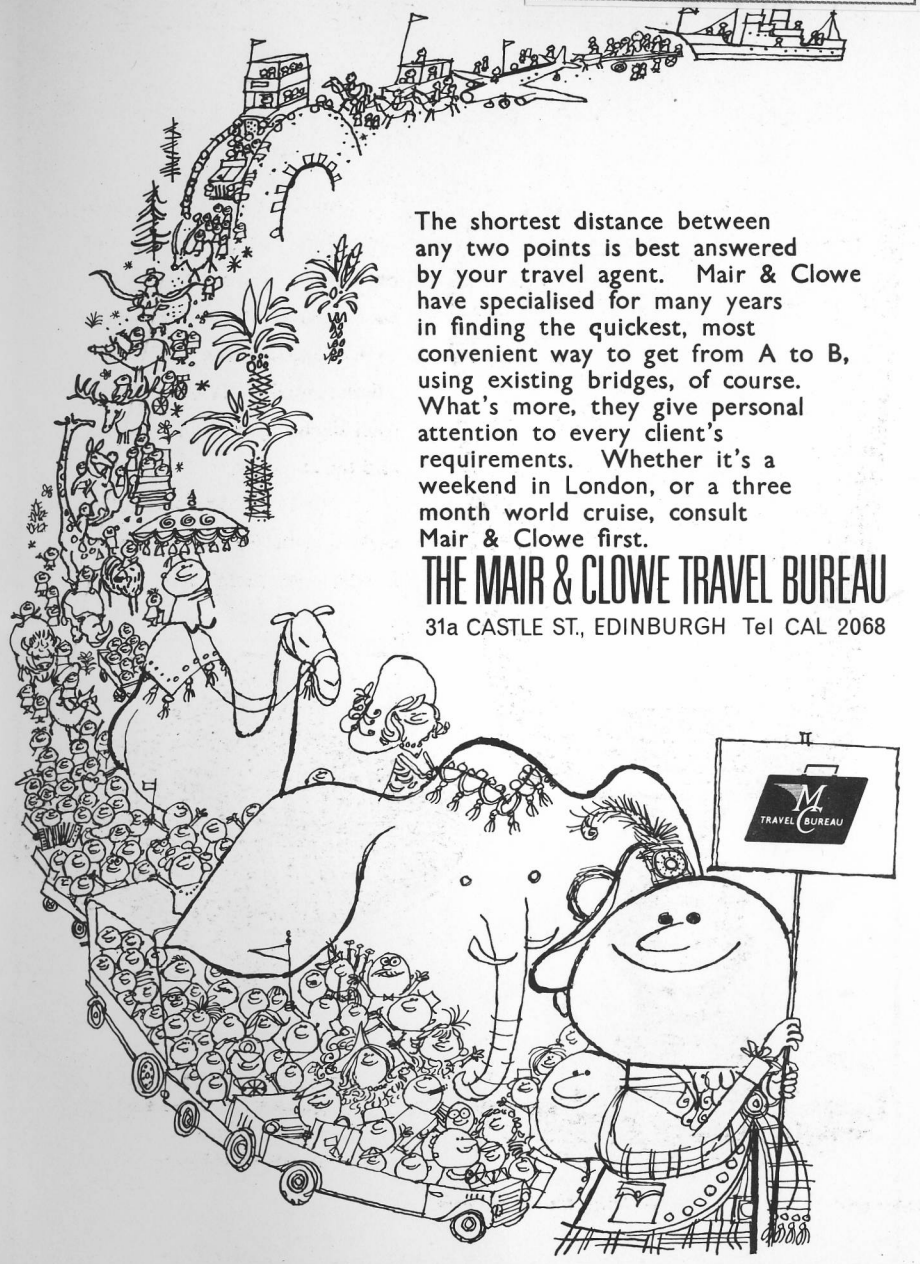
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