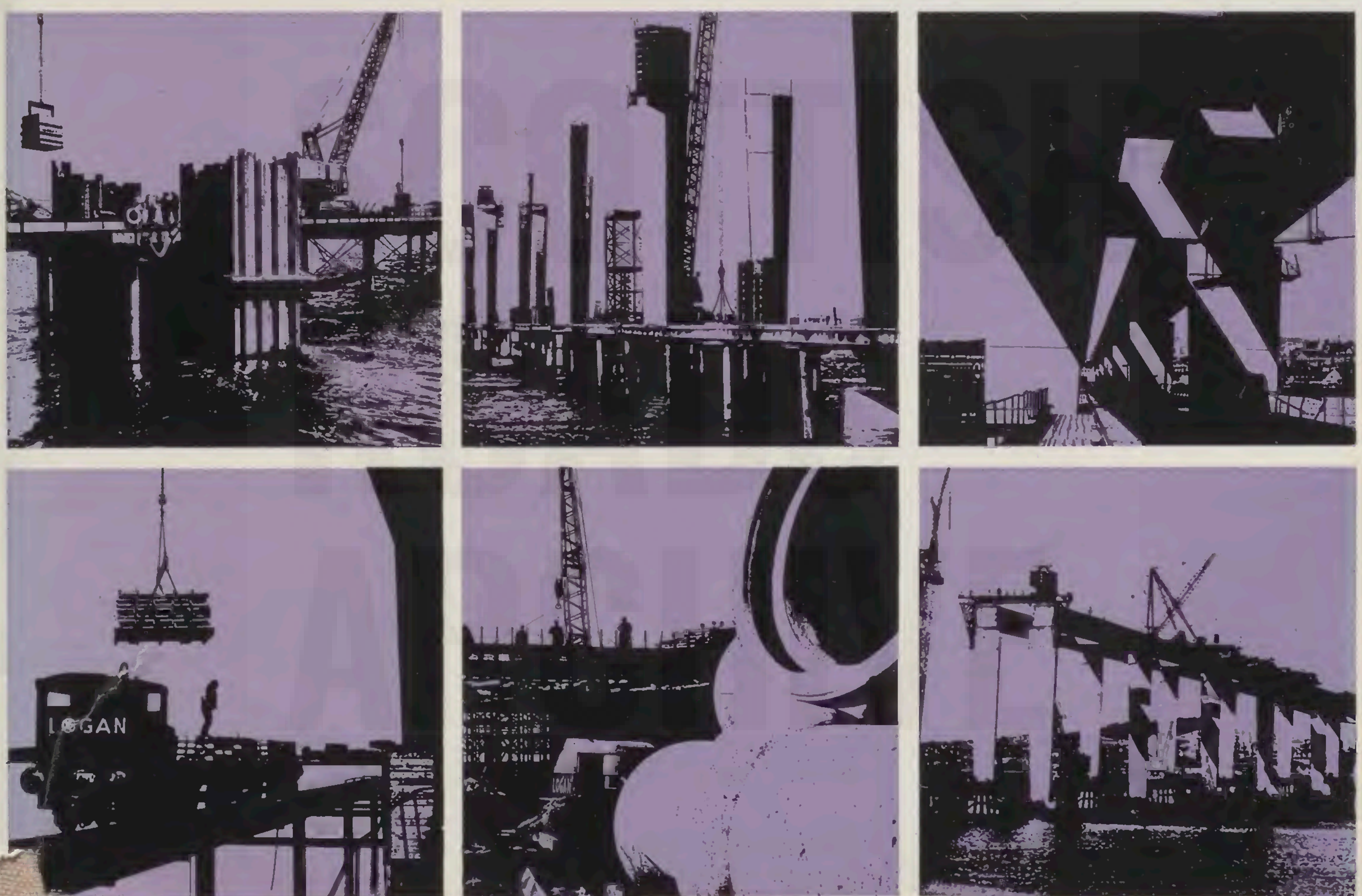
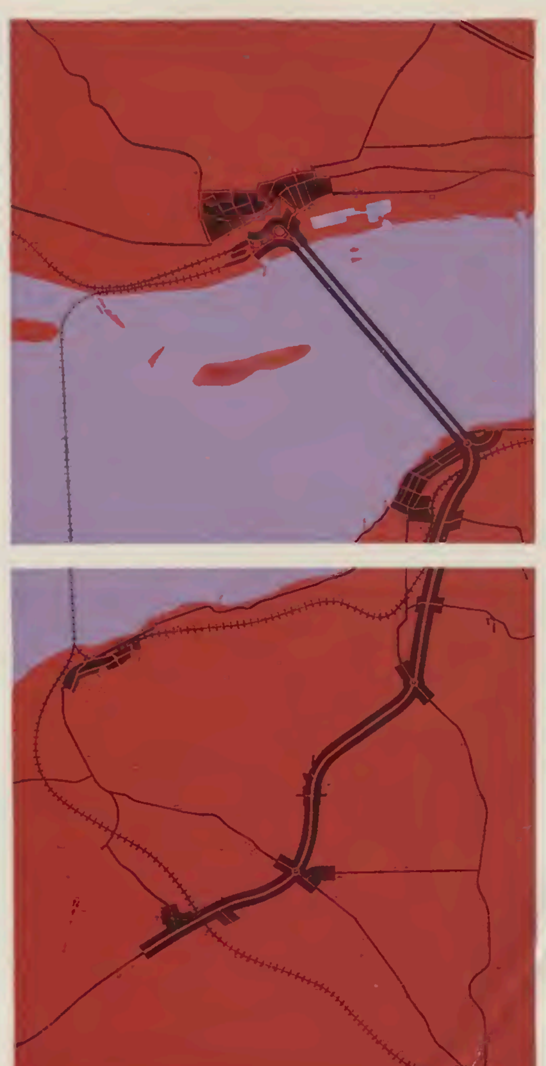
The Tay Road Bridge

The story of the Tay Road Bridge, opened by Her Majesty Queen Elizabeth the Queen Mother, Thursday, 18th August, 1966





Work on the Tay Road Bridge began in March, 1963. It was opened to traffic in August, 1966.

The bridge is 7,365 feet long, the longest river crossing of any road bridge in Britain.

The number of spans is 42.

Each of the two-lane carriageways is 22 feet wide. The central footpath is 10 feet wide.

The deck rises from 32 feet above sea level at Dundee to 125 feet in Fife. The gradient is 1 in 81 throughout.

Concrete foundations support twin columns of developing parabolic shape. The columns support steel plate box girders 12 feet wide by 10 feet deep with a composite top flange of concrete forming the roadway. The girders range from 10 to 20 feet deep over the navigation channel.

There are 3.6 miles of approach roads on the Fife side. There are toll installations and network roads of an inverted trumpet design at Dundee.

The quantity of concrete used was 140,000 tons.

The weight of mild steel bar reinforcement used was 4,600 tons.

The weight of structural steel used was 8,150 tons, most of it in the box girders.

The cost of the bridge and its approaches was £4,800,000 (excluding the cost of land and interest charges.)

Before the bridge was built, the shortest route by road from the Fife abutment to Dundee was via Perth, a distance of 50 miles.

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This book has been prepared for the opening of the Tay Road Bridge by Her Majesty Queen Elizabeth the Queen Mother on Thursday, 18th August 1966.

There has been talk of a Tay road bridge for the better part of a century, but so long as railways carried most of the country's goods and passengers the cost could not be justified. It became acceptable only when the motor car began to put traffic back on the roads in the 1920s, and even then the plan foundered. A firm of consultants reported to the Minister of Transport in 1929 that a high-level bridge could be built for £3 million or a low one with opening spans for a little over £1 million, prices so modest that the Government offered Dundee an 80% grant; but Dundee was hard pressed by the slump and turned both plans down.

There was more talk in the late 1940s, but wartime leeway had to be made up and other projects were thought to be more urgent. In the 1950s a public appeal by the Lord Provost of Dundee raised enough money to allow test borings to be made, and these established that the bridge was possible. At last in August 1955 an exploratory body called the Tay Road Bridge Joint Committee was formed with the Lord Provost of Dundee in the chair. Its members were drawn from the Town Council of Dundee and the County Councils of Fife and Angus, and after four years of discussion they appointed a civil engineering consultant. Six months later, in June 1960, he presented a plan to them. It was accepted.

The Government made it clear that it would sanction the bridge only on the basis that the capital and running costs would be met by tolls. With some reluctance the committee accepted this, and a bargain was made under which the three local authorities agreed to become responsible for a share of the money needed to build the bridge. The remaining share was to be advanced by the Government. All the money so advanced had to be repaid in due course to the four lenders, over sixty years if necessary. Of the local authorities' share of the capital Dundee loaned 63%, Fife 27% and Angus 10%. Plans were deposited for a Parliamentary Order in October 1961, and Parliament approved them in August 1962. The committee, its task completed, then wound itself up and, with a few minor changes, became the Tay Road Bridge Joint Board under the terms of the Order. It is this body which has controlled the building of the bridge. It first met on September 3, 1962.

DESIGN

Plans and problems

The bridge was designed by William A. Fairhurst. When he was called in by the committee and asked to prepare a preliminary plan he had three factors to consider. These were engineering, money and appearance.

Money was more than usually important because this time, in contrast with the situation in 1929, the Government was not making a grant: it was lending money which would have to be repaid, and the repayments were expected to come from tolls. If the bridge cost too much, the tolls would be too high and motorists would prefer to take the long way round by Perth. The appearance of the bridge was also bound up in this: the designer would have been at pains to make it handsome in any case, but here he felt good looks were especially important because an attractive bridge would earn more tolls than an unattractive one.

However, first things came first. The line of the bridge had to be determined, and here it was found that the shortest way across the river was not the cheapest. Unless shipping in Dundee Harbour was to be obstructed, the piers on the shortest route would have to be widely spaced, and bridging the long spans would push the price up to nearly £7 million. Another possibility was to deliver the traffic well clear of the city centre, but that line was too long and in any case the river bed was littered with expensive Post Office cables. The cheapest route made use of the fact that the tidal harbour in Dundee could be filled in, offering a convenient landfall for the bridge. This line was 7,300 feet long and delivered its traffic into the heart of Dundee.

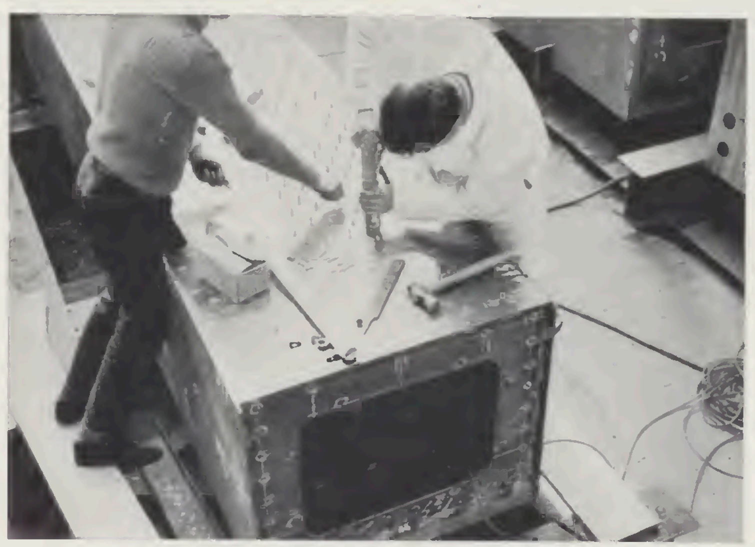
It was not an easy decision to make at a time when most cities were spending large sums on diverting traffic from their centres, but the advantages of the harbour route outweighed the disadvantages and could not be ignored. It was cheap. Preliminary borings and a geophysical survey showed that the river bed was suitable, and the site was clear of underwater cables. The bridge was replacing a ferry service, not a main trunk road, and though traffic was expected to grow it was not likely to create a major problem. Moreover, it would be delivered on to a ring road which would disperse it and carry it clear of the actual city centre.

But the main advantage lay in three important facts. The first was that the buildings on the Dundee terminal had long been in decay and would cost little to demolish. The second was that the deep channel by which shipping navigated the otherwise shallow Tay lay close to the Fife shore. And third, high ground lay above that same shore.

All three of these affected the cost of the bridge. No new property would have to come down, and it would be possible to design the bridge in such a way that it would start near sea level in Dundee and rise steadily as it crossed the river until it reached the high ground at 125 feet above sea level. It was not necessary to build tall piers all the way. The height which would allow shipping to pass under the bridge came exactly where it was needed, over the deep channel.

The next stage was design, and here few conditions were imposed by the site. In building deep-water bridges such as, for example, the Forth road bridge, the site determines the design because there is hardly any choice in placing the piers and everything else follows from that. There was no such difficulty at Dundee. At low water the river in some places was as little as 7 feet deep, and it was nowhere deeper than 58 feet at high water spring tides. Within reason the piers could be built anywhere. The problem was therefore one of efficiency, of choosing spans which would do their work at least cost.

The designer chose 120-foot spans of prestressed concrete;



Tests on the box girder model showed that the bridge would be able to support its own weight plus five times the maximum weight of traffic.

The bridge was modified only slightly after these preliminary sketches of the Dundee terminal were drawn. Below, viewing platforms over the tollbooths project beyond the bridge and give views of the complete crossing. Opposite, traffic is delivered into the heart of the city, but the ring road carries it clear and prevents congestion. The building enclosing a square, bottom right, is the City Chambers.

but when a scale model of the river was built and hydraulic tests were run on it, it was found that spans so closely spaced could cause Dundee harbour to silt up. Spans of 180 feet were chosen instead, and the designer sat down to consider how they would be constructed. As they were virtually the key to the whole bridge, they are worth considering in some detail.

Their design was based on the fact that concrete is strong when it is compressed but not so strong when it is under tension, whereas steel stands up well to tension. The plan was to build box girders, like immensely long square steel tubes, and then bond a concrete road on top of them. Steel and concrete would be one structure, and because the concrete was on top with the weight of the traffic pressing directly on it, it would be in compression and therefore strong, thus allowing thinner steel to be used on top and sides. The girders have in fact been made of steel only $\frac{3}{8}$-inch thick top and sides, but $\frac{7}{8}$-inches thick on the bottom where the stretching forces fall, an arrangement giving maximum strength at minimum cost.

This was theoretically a sound arrangement, but as few structures like it (and nothing on such a scale) had ever been built with modern materials it was felt that the theory should be tested. To prove the design in practice one of the biggest series of model tests carried out in this country for a century was embarked upon. A quarter-scale model of a girder was made and then tested to destruction at Glasgow University, and a 1-in-40 model of a bridge section was tested in the University's wind tunnel. The results showed that the bridge would be able to support its own weight plus five times the weight of traffic which it was ever likely to bear, and so far as wind was concerned the safety factor was at least four. One other important test concerned the security of the bond between the concrete deck and the steel girders, for if it were weakened by the passing and repassing of traffic the strength of the bridge would be impaired. The model was loaded and unloaded 2,000 times with a weight equivalent to a full capacity of 10-ton lorries standing nose to tail, but there was no loss of bond whatever.

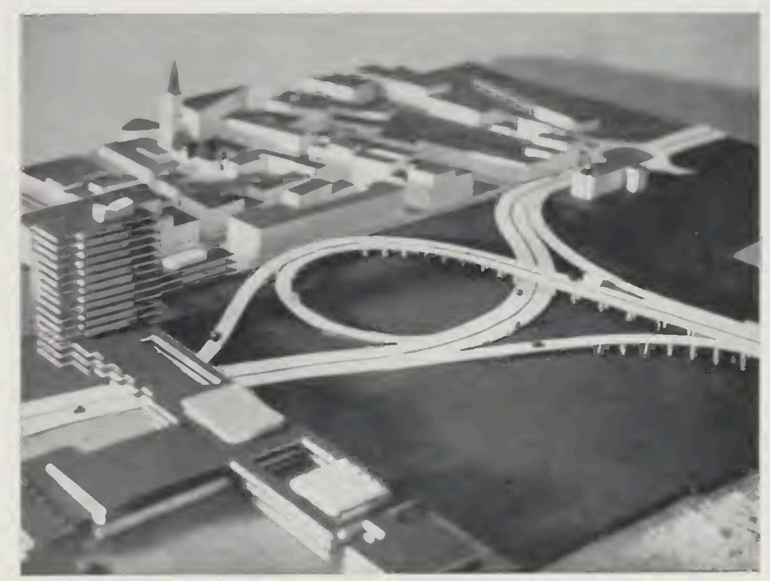
In fact the tests confirmed the theory. The design was intrinsically strong and yet made very economical use of materials.

Incidentally there was a strong dash of common sense as well

as technical expertise in the design of the girders. They had to be stiffened, so the stiffeners were put inside, away from the weather. The painters in future will climb inside through special doors and tackle the awkward corners in completely dry conditions. Also, since girders of this size expand and contract on warm days and cold, a gap of about two inches has had to be left between them, like the gap at the end of each rail on a railway line. It was foreseen that painters would never be able to penetrate this, so the concrete on top of the girders has been carried down the ends as well and makes painting unnecessary.

But before any of this could be built full-scale, one major matter remained to be decided, the appearance of the bridge.

The cheapest way to build it would have been to make all the girders the same length and then mass-produce them, but the appearance would have suffered if this had been done. Bridges have a curious habit of exaggerating the normal effects of perspective. Everyone knows that objects which are equal distances apart appear to be wider apart the closer they are to the observer, and the eye makes allowance for this. For some reason the eye does not make the allowance correctly for bridges.



Though most of it is empty space today, the ground beside the Dundee terminal will be landscaped, with some public buildings.

If the piers are all built equal distances apart, the spans closest to an observer on the shore seem too wide.

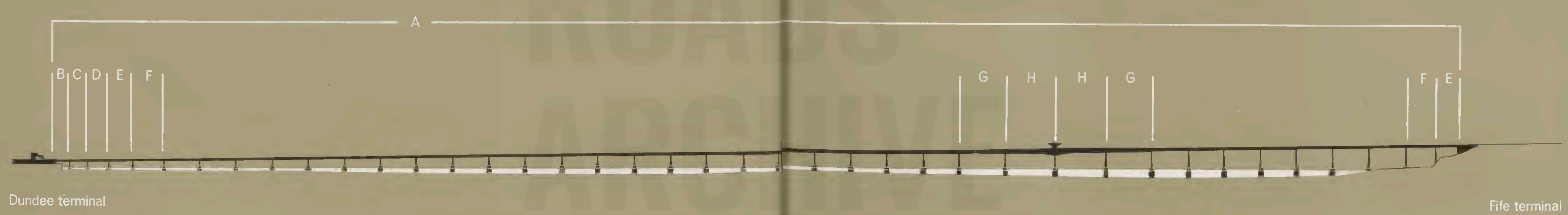
This can be proved by looking at the Tay road bridge today. The piers seem equally spaced, but they are not. In fact the span nearest the shore is 80 feet long, the next 90 feet, the next 105, the next 125, the next 150, and then off they go—180, 180, 180—until they taper down for the far shore. The only break is at the deep-water section, where there are four navigation spans, two of 230 feet and two of 250. It has all been very cunningly done. The eye tells the brain they are equally spaced. A further advantage of reducing the spans near the Dundee shore was that it enabled the box girders to be tapered gradually from the normal depth of 10 feet to a depth of 5 feet, thus lightening the appearance of the bridge.

The other problem of appearance concerned the piers, which started 20 feet high on the Dundee shore and ended at 125 feet in Fife. It would have been a simple matter to design a pleasant-looking pier of one height or the other, but to design one which was handsome at one height *and* the other *and* at every other height between was something else again. Nor did the problem end with appearance. The mathematics were bound to be tricky and there was the danger that a pier designed for beauty would be excessively awkward to build.

The designer's solution was an elegant one, the pier which appears so often in these pages, almost round in section at the bottom and flattened at the top, like a tube of toothpaste standing on its head. From the engineering point of view this design was sound: the longer the pier, the thicker it grew towards the base and the stronger it became. From the visual point of view it was also sound: no matter how the height varied, the proportions were beautiful. Also, the piers were as simple to construct as such a complicated shape could be. All the vertical lines were straight.

The other basic factor considered in the early stages was, of course, the capacity of the bridge. The answer seemed simple enough. A survey was made and produced the forecast that 3,200 vehicles a day would use it when it was first completed. To allow for future traffic growth it was therefore designed for three lanes of traffic and a capacity of 10,000 a day. Four lanes would have been better, but the income from tolls would not stretch to it until it occurred to the designer that so far as footpaths were concerned we were creatures of habit: we had footpaths on both sides of the road because there were shops or houses on both sides. There were no shops or houses on the

The length of the bridge, A, is 7365 feet. Seen by an observer on the shore all the spans seem equal, but this is the result of a carefully contrived optical illusion. If they had in fact been made equal, they would not appear so: those near the shore would seem wider than the rest. The spans are therefore shorter towards both shores, as the drawing shows. B is 80 feet, C 90 feet, D 105 feet, E 125 feet, and F 150 feet. All the others are 180 feet, except at the navigation channel, where G is 230 feet and H 250 feet.



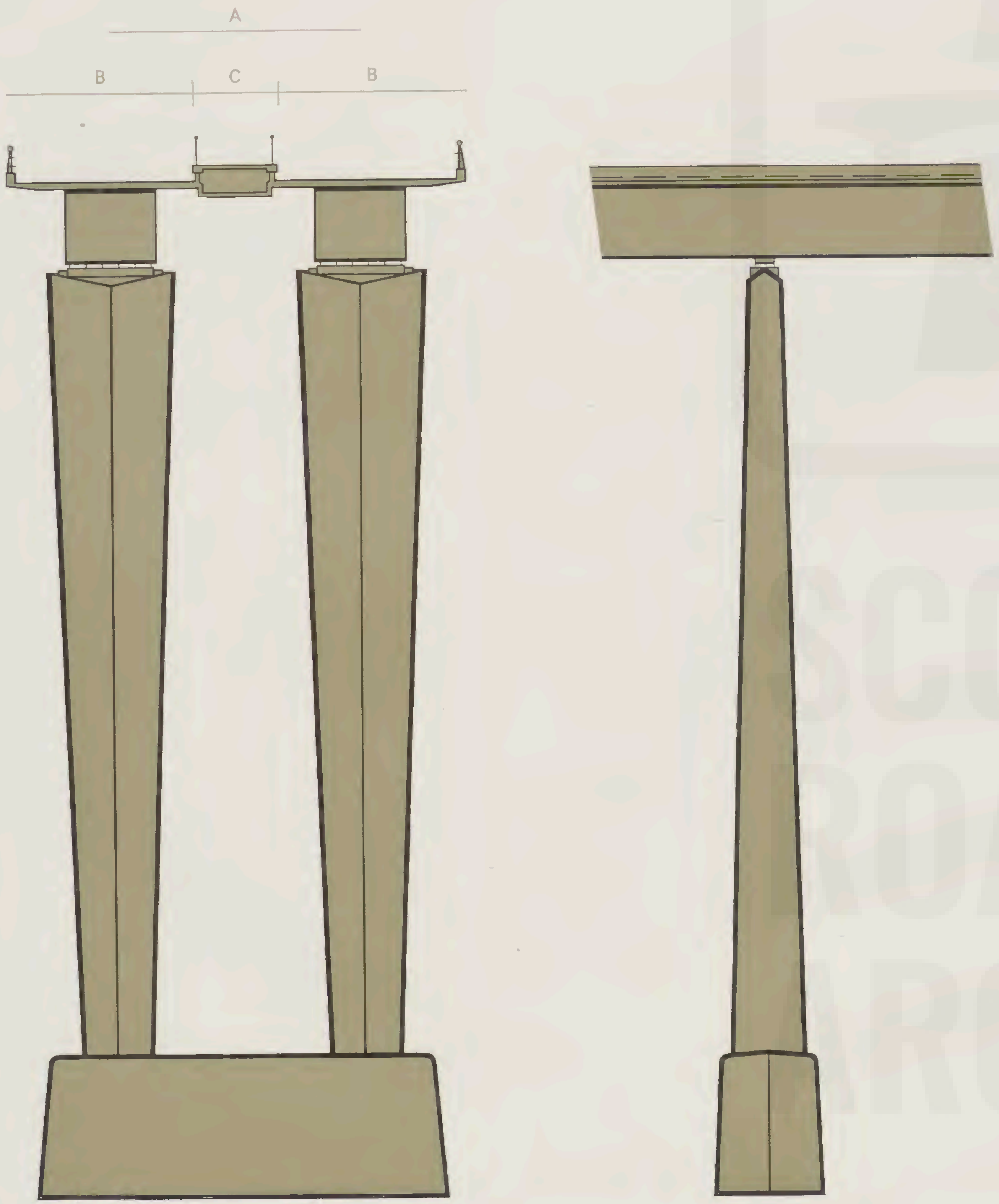
Tay bridge, so why not have one footpath down the middle? This has been done. The money saved has provided a fourth traffic lane.

The central path slightly diminishes the view of the river for people crossing on foot, but a virtue has been made of it. Observation platforms have been built, one cantilevered out over the tollbooths on the Dundee side and another over the shipping channel, not only giving downward views of the river but also spectacular views of the bridge from the bridge. Also, a feature has been made of the central pathway, which has been paved in random tiles of different colours and given slender aluminium handrails. It is extraordinarily attractive, and for many years to come should make the bridge Dundee's favourite Sunday afternoon walk.

All these plans were made and the tests completed by August 1962. The bridge then had to be built.

One of the most ingenious features of the bridge is the appearance of the piers, designed to look elegant from any angle and when built to any height. The bridge slopes continuously upwards in its passage from Dundee to Fife and the piers in consequence grow taller: to create a pier which remained handsome no matter how much of its base was removed was not easy. The photographs show some of the attempts made before the final version (opposite) was evolved.

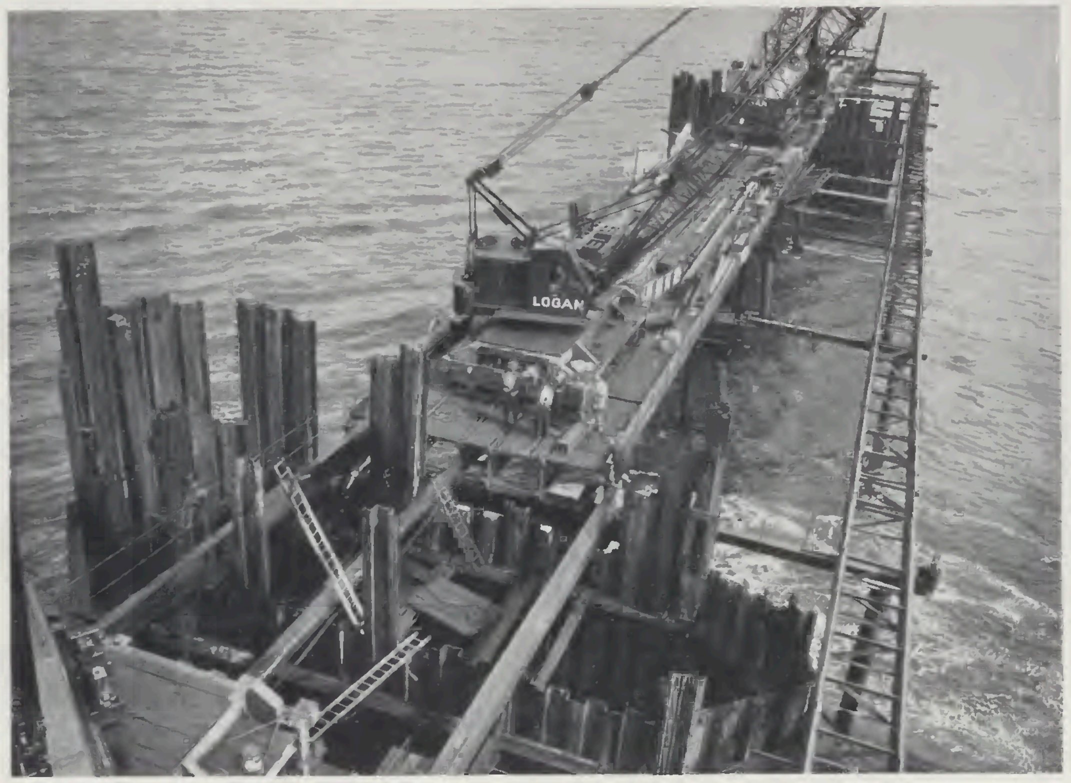
A: The distance from centreline to centreline of each pair of piers is 32 feet.
B: Each carriageway is 24 feet 9 inches wide.
C: The walkway in the centre of the bridge is 9 feet 1 inch wide. The service duct under the walkway shows clearly in this elevation.



BUILDING

The work gets under way

Using a temporary bridge instead of barges as a base from which to build the main bridge allowed work to continue in bad weather.



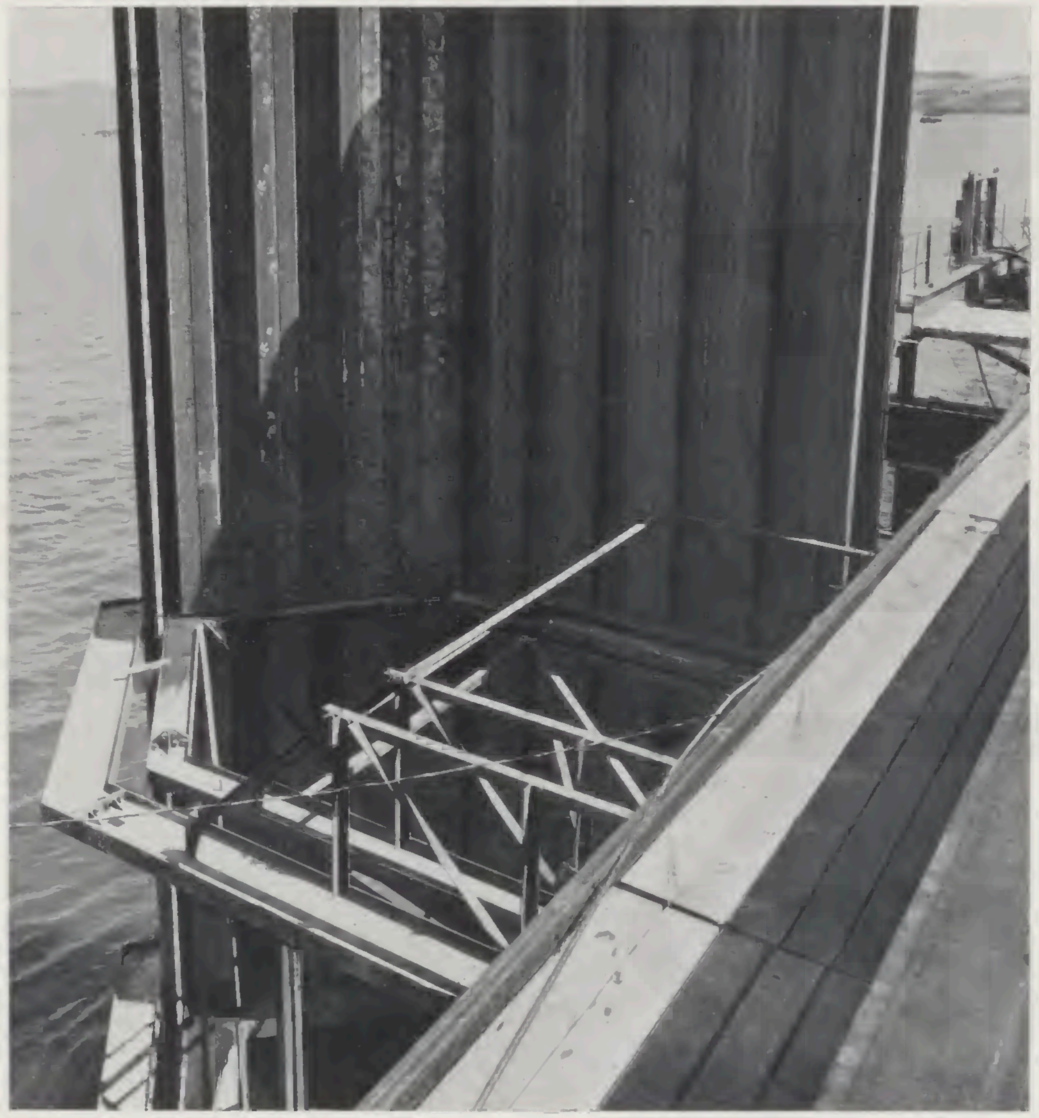
All bridges should be started in March, with the winter over and spring not properly begun; and most contract dates are in fact arranged so that this can be done. But good intentions are seldom enough: the paperwork drags on and little is done on the site until October.

The designer was determined that this would not happen here. The finances of the bridge had been arranged in record time, the work had gone out to tender in November 1962 only three months after Parliamentary approval had been given, and the tenders were due in by January 19, 1963. The early spring start could become a reality only if the lowest tender fell within the designer's estimate. If the price was right, the momentum could be maintained. If it was too high, there would be renewed discussions and fresh planning; and the best of the year would be lost.

The estimate for the main contract was £3,820,000. Duncan Logan (Contractors) Ltd., of Muir of Ord, tendered so late that their offer had to be flown to Dundee and arrived with only 15 minutes to spare; but when it was opened it was found to be the lowest. The Board accepted it on the spot, and half an hour later a letter had gone to the contractors to tell them so. Mr. William Logan then looked at the calendar and saw that the date on which he was due to start, March 31, was a Sunday. He did not work on Sundays. The first pile of the Tay road bridge was driven on March 29, 1963, two days early. And the contract price was £3,823,153 16s 7d.

The contractors had based their successful tender on building not from barges as most of the other tenderers had proposed to do, but from a temporary bridge in accordance with the designer's intentions. It appeared at first sight to be a costly method, but they reasoned that it would save money in the end. It would be possible to work in nearly every kind of weather and at all states

Sheet piles driven into the river bed formed coffer dams for the piers. When underwater techniques had built up the concrete to within 20 feet of the surface, the cofferdams were pumped out and men went down to complete the piers.



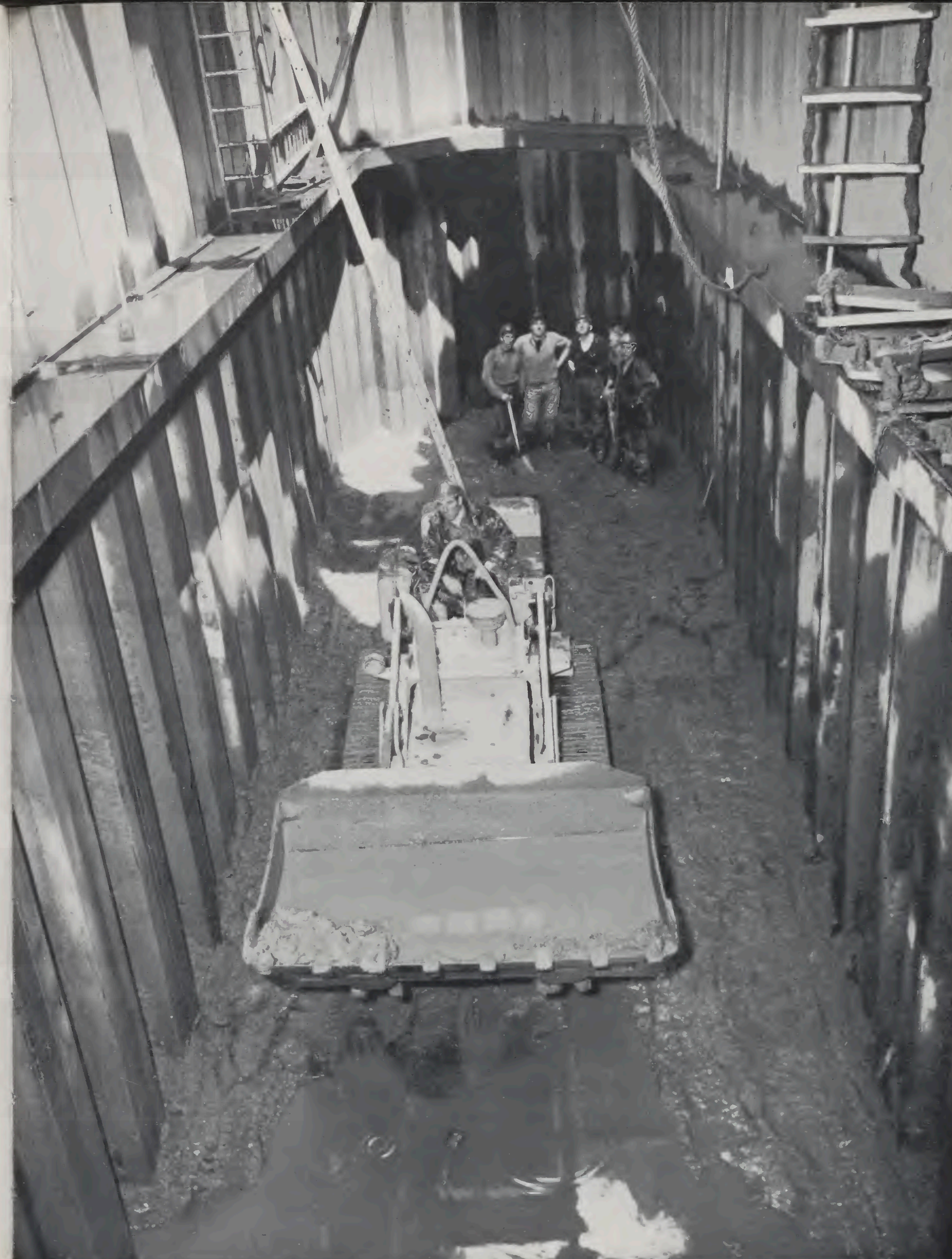
of the tide, whereas barges would be lucky to work three days in four. Barges would mean a floating crane, and at best could be moored only to a few piers at a time. With a temporary bridge the contractors would be able to tackle the piers in any order they chose and work on any or all of them at once.

Most big bridges are built from both sides and meet in the middle, but the filled-in dock at Dundee was so convenient that it was planned to build from the Dundee side only. Fabrication, marshalling and storage areas were set up, a concrete batching plant and engineering workshops were built, and a fabrication yard was laid out for the temporary bridge sections. The temporary bridge began to push out from the Dundee shore, and the building sequence started.

The first step was to provide conditions in which the foundations of the piers could be built, no easy matter in a cold river which ran six knots at springs and on occasion made it impossible for divers to work for more than 15 minutes at a time. So when the temporary bridge reached the site of a pier, a cofferdam made of sheet piles was first of all driven into the river bed, not with the idea of keeping the river out, but of creating an area of still water by putting, as it were, a steel fence round it.

Close to the shore where bedrock lay near the surface, the sand and silt were dug out and the piers were planted directly on the rock. As the depth increased, steel piles were driven inside the cofferdams, going down to bedrock or until they could be driven no farther; and these formed a foundation for the piers.

The still water was necessary because the two methods of building up concrete round the piles, techniques known as underwater grouting and tremie concreting, could not otherwise have been used. The grouting method involved roughly levelling the river bed inside the sheet-pile "fence" by using grabs, and then driving in king-piles as far as they would go. Ready-mixed



sand and aggregate were then tipped on top of the king-piles, and into the *bottom* of this heap the pumps delivered a stream of colloidal grout, a concrete mixture which filtered up through the aggregate and then set.

The tremie technique achieved the same result in a different manner, and may best be understood by visualising an ordinary wide-mouthed filler of the type used for filling bottles, but magnified many times. The pipe of the filler was lowered to the river bed and a canvas bag was placed at the top of the pipe, where it opened out into the wide upper part of the filler. Concrete was then poured in, forcing the bag down the pipe to the river bed and at the same time forcing out the water. When the concrete column reached the bottom, the pipe was gradually lifted clear. So long as concrete was fed continuously in at the top, it was possible to keep on raising the whole contrivance, leaving a pillar of concrete behind it. Hence the cofferdam. Without it the Tay bridge concrete poured by either of these methods would have been washed away before it had time to set.

When the concrete reached a point within 20 feet of the surface the cofferdam was pumped out and concreting continued in the open air to a point just below low water mark.

To the layman this may seem a curiously elaborate method. Why not, he might ask, pump out the cofferdam at the start and build directly on the river bed as was done with the in-shore piers? The answer is simply that the water pressure would have been so great that the sheet-piling "fence" would have collapsed. Rather than build elaborate high-pressure caissons, it was preferred to use underwater concreting until the piers had risen far enough for the cofferdams to take the strain.

With the concrete just below the surface the shuttering was set and the boat-shaped piers were cast. Finally the twin columns were cast on top of them.

The columns, as we have seen, were of complex design, and expensive and extremely accurate shuttering had to be used in order to cast them. The columns, 100 feet tall on the Fife shore, decreased 2 feet $2\frac{1}{2}$ inches for every 180 feet of bridge, so the simple way of using the shutters would have been to trim a piece off them each time they were used. Unfortunately the bridge was being built from the wrong shore: the columns were growing longer, not shorter, as the work progressed.

The problem was solved by leapfrogging, by moving out into the river, building the longest columns first, and then working back towards the shore.

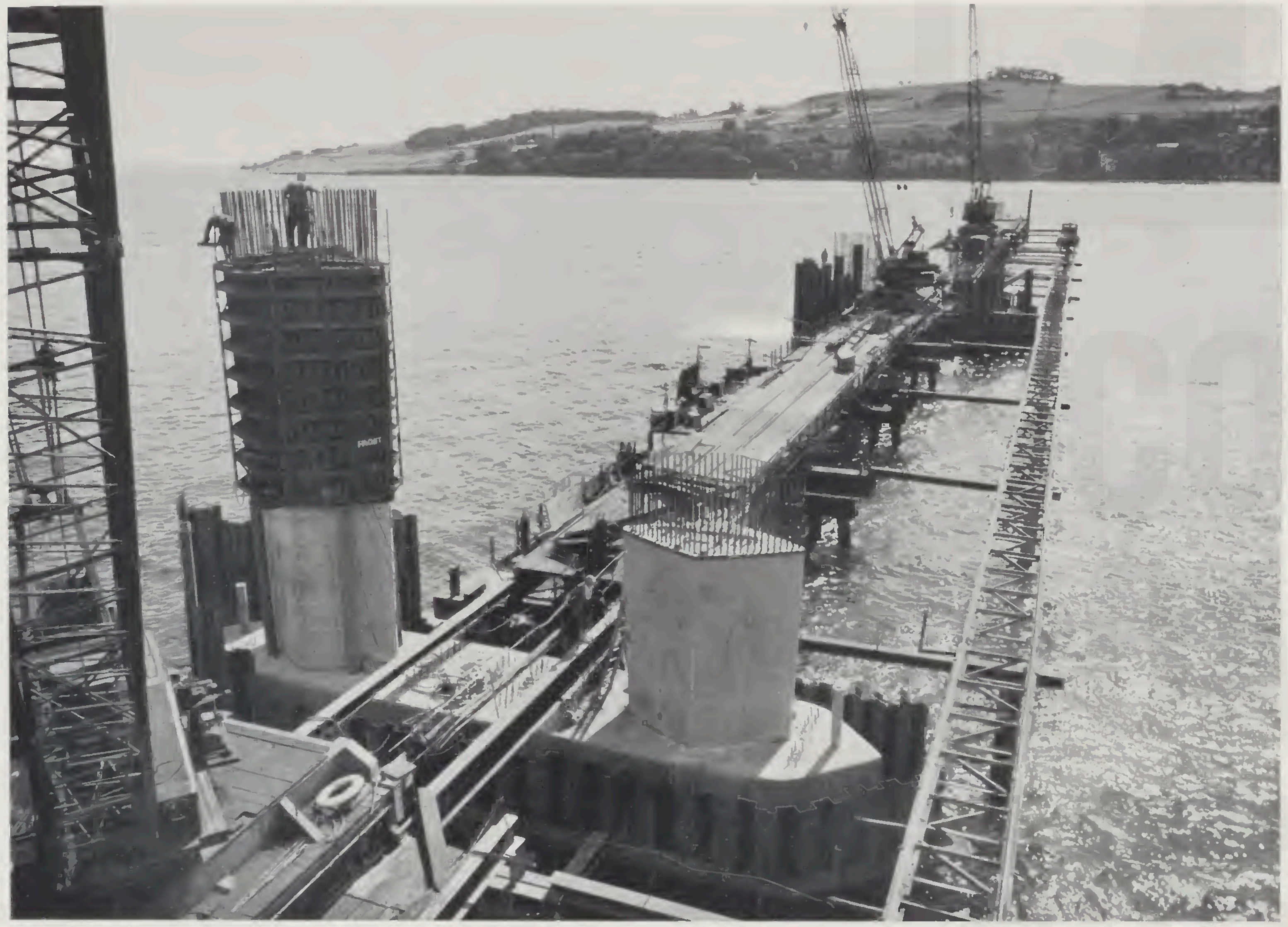
One of the most delicate tasks in the building of the bridge was setting up the shutters on top of the piers so that they stood absolutely plumb, for each half-section stood 17 feet high, measured 16 feet at its widest, and while it was being manoeuvred into place could be blown as much as a foot sideways by even a 15-miles-an-hour wind. As each section of the column was cast, the next section was socketed on top and carefully adjusted by four small jacks until it stood true.

The double line of columns advancing into the river straddled the temporary bridge, so it was possible to run the big box girders out on a railway line one at a time until each lay in the centre of the temporary bridge a few feet above the water, below and slightly to one side of its final position on top of the columns. Most of them were 180 feet long, built by the Caledon Shipbuilding & Engineering Co. Ltd. in three sections and then welded together at the bridge terminal; and they weighed 200 tons apiece. Four massive plate chains were fixed to each girder, two at one end, two at the other, and connected to steel lifting frameworks far above on top of the columns. Jacks then lifted the girder, still over the centreline of the bridge, until it cleared the column tops and could be slid sideways into position on its stainless steel bearings. When the girder on one side of the bridge had been lifted, its twin was brought out and lifted into position on the other side. The gear was then moved 180 feet forward and the sequence gone through again for the next pair of girders.

When a span had reached this stage of construction it consisted of two long box girders, each supported by a pillar at each end, so that it looked like two narrow bridges running

Below water the cofferdam itself formed the mould for each pier. Near the surface shuttering was set to produce the smooth boat-like outline in the centre photograph. Shuttering was then set for the twin columns, one of which is shown on the right.

The temporary bridge allowed the piers to be tackled in most states of the wind and tide, and in any order—an important point, since the shuttering for the piers was expensive and the piers increased in height as the bridge advanced across the river. The freedom of movement offered by the temporary bridge allowed the builders to leapfrog out into the river and then work backwards, cutting a piece off the shuttering after each pair of columns had been cast. Right, the columns near the shore are all complete, and a new series has been started. The columns farthest out in the river are the most advanced.



side by side. The next task was to build the roadway on top and thus link the two parallel sets of girders. This was not done by building a single concrete structure the full width of the bridge. Each dual carriageway was cast as a unit, cantilevering out from each side of its girder, and leaving a narrow gap down the centre of the bridge. Precast units were then slotted into the gap to form a duct for cables and water mains, and further precast slabs were fitted on top to form the central pathway. The bridge is in effect two parallel bridges with connecting members at intervals and the service-duct-footpath dropped into position in the middle.

All the kerb units were precast by the contractors at Conon Bridge and Beauly and sent south by road, as were the 7′6″ square slabs of random tiles for the footpath. (These are not so random as they look. Wherever possible each colour is arranged in a series of knight's moves, that is either two forward and one to the side, or one forward and two to the side.) The aluminium handrails and crash barriers were also made by the contractors in the north at Muir of Ord. They were specially designed for the Tay bridge and were the first major application of aluminium to the construction of crash barriers in Britain. They proved extremely easy to handle. One of the odder spectacles during the building of the bridge was of workmen carrying apparently impossible lengths of railing single-handed.

The central duct carries Post Office cables and a 24-inch water main in addition to its own lighting cables. The main at present works from existing supplies in the normal way, but it has been designed for high pressures. When future development calls for more water, pumping will speed up the flow.

One other major construction problem remained as the bridge advanced across the river. It would pass high over the shipping when the navigation channel was reached, but the temporary bridge would not. The temporary bridge ran low over the water throughout its length. Somehow it would have to open to allow shipping to sail through. This was achieved by building the permanent navigation spans well in advance of the others and then hanging a temporary opening bridge from them. To the layman this may not seem especially difficult, but it was in fact a considerable feat. The temporary structure bridged a gap of 200 feet in two halves—the same span as the Tower Bridge, which in principle it resembled.

Three-and-a-half-miles of approach roads carry the bridge traffic on to the Cupar-St. Andrews road and beyond into Fife; and the land surrounding the Dundee terminal has been partially landscaped, first step in a plan which will make this area a fitting landfall for the traveller approaching Dundee from the south. A swimming pool and various other public buildings will be grouped there, and the unused ground will be landscaped.

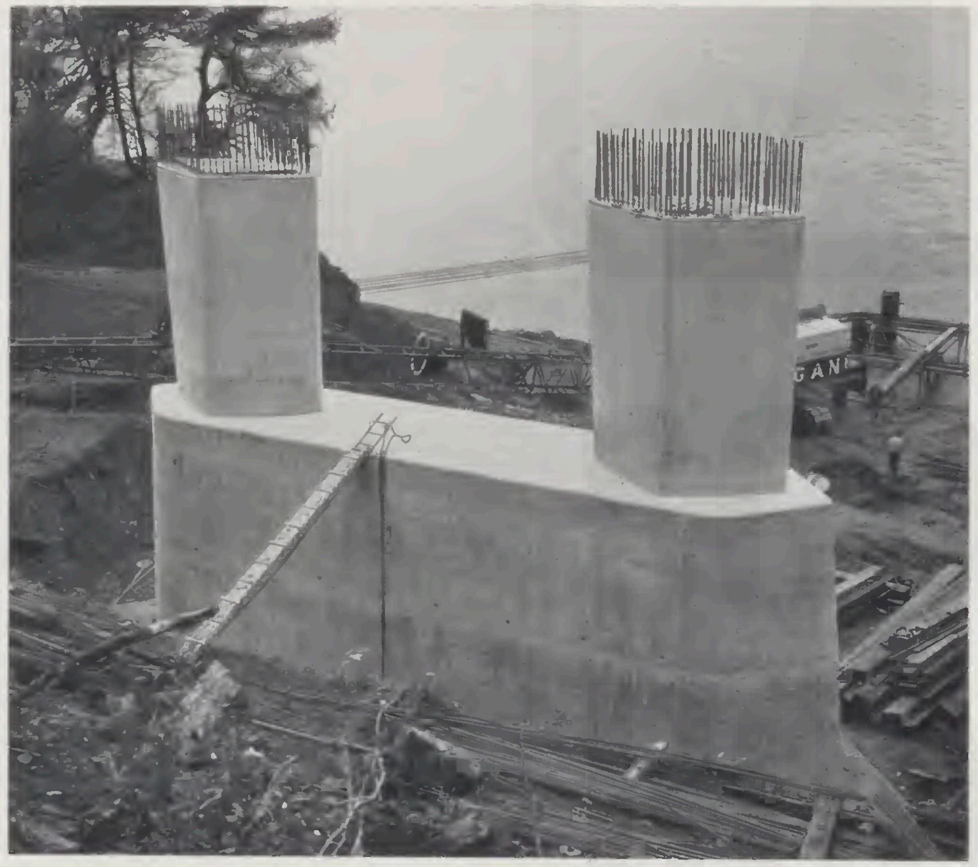
The bridge was built in a little under three-and-a-half years, during which time it caused some unavoidable interference with the centuries-old ferry service it was to supersede. Most of the work went according to plan; though not, alas, without accident. Three hundred and sixty men worked on the site during the peak period. Five of them were killed, two by falls from the bridge and three when 100 feet of the temporary bridge fell into the river. Another accident, fortunately without loss of life, occurred when the ferryboat "Abercraig" had an engine failure and crashed into the temporary bridge. Despite a gale-force wind, the passengers were taken off and led along the temporary bridge to the shore. The only other mishap involved a coaster which failed to find the navigation channel one foggy day and hit the temporary bridge, luckily at a point where the damage was unimportant.

In addition to those who worked on the bridge itself, approximately 200 were involved in fabricating the girders, concrete work and railings off-site.

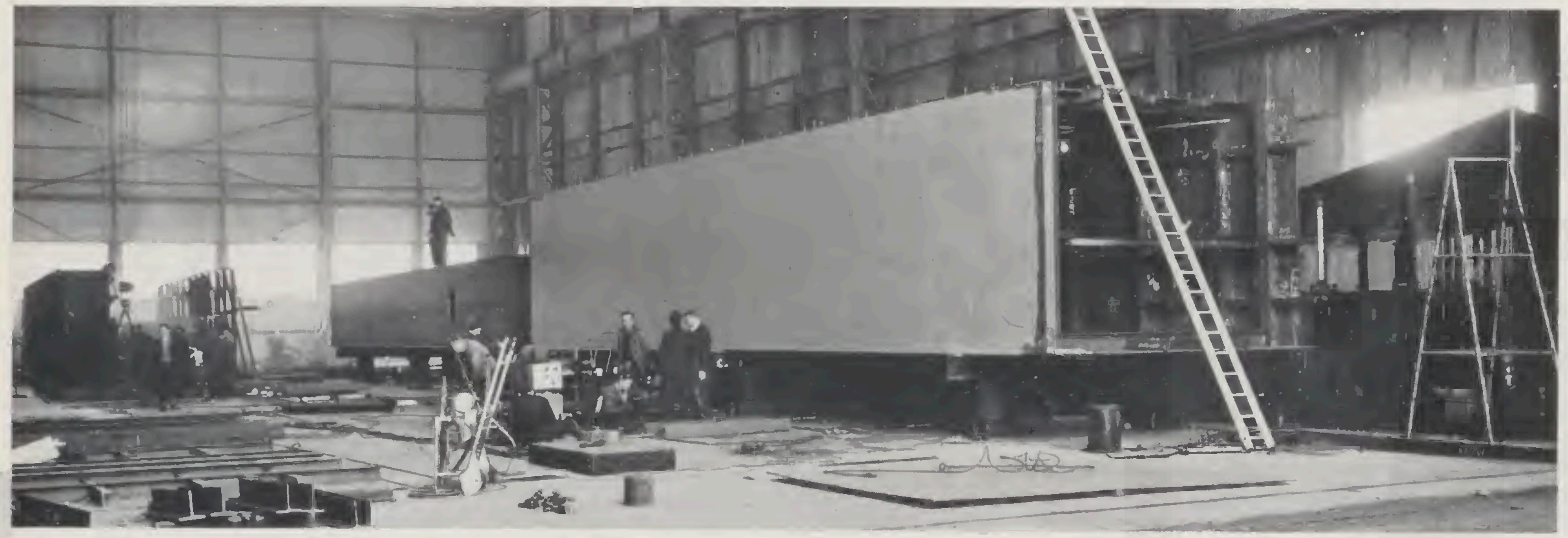
Now that the bridge is about to take its place in the transport system of the country, the final cost is being calculated. The original contract allowed increases in wages and the cost of materials to be taken into account; and these, with a few extras not allowed for in the contract, total roughly £200,000. The final bill the Board will have to meet for the main bridge contract will be approximately £4 million. Allowing for approach roads, offices, landscaping, tollbooths and equipment, compensation for ferries, purchase of land, fees, and interest on capital, the overall total will exceed £6 million.

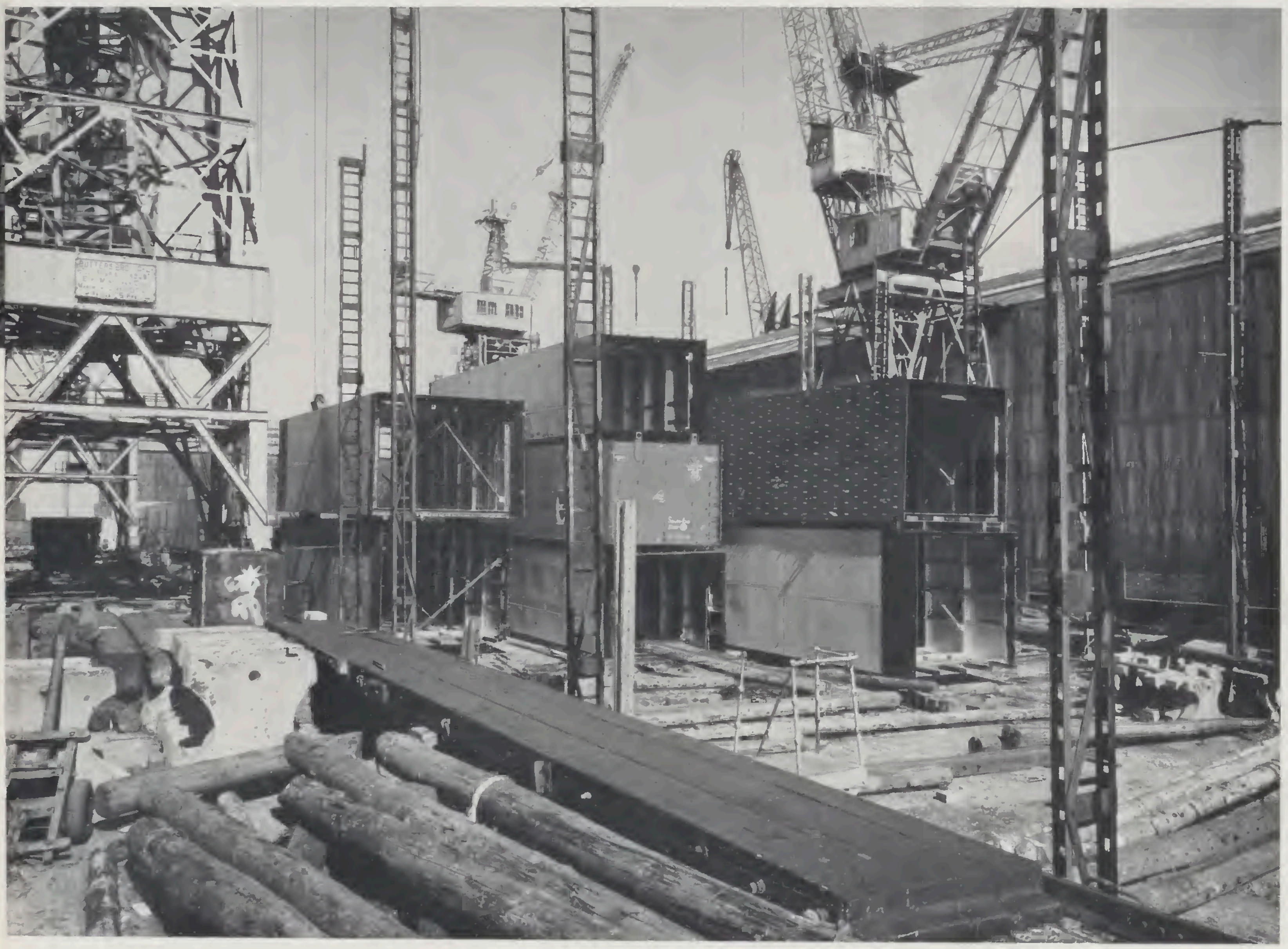
As prices go today, it is a bargain. Scotland has gained a useful, safe and handsome bridge at remarkably low cost.

On the Dundee side the columns are complete. In Fife, columns already almost as high are only a base. Opposite page, the columns reach their maximum height as the bridge advances, then shorten again as the shore is reached and the ground rises to meet the approach road. Setting up the shutters for these piers had to be done with great accuracy, difficult work in

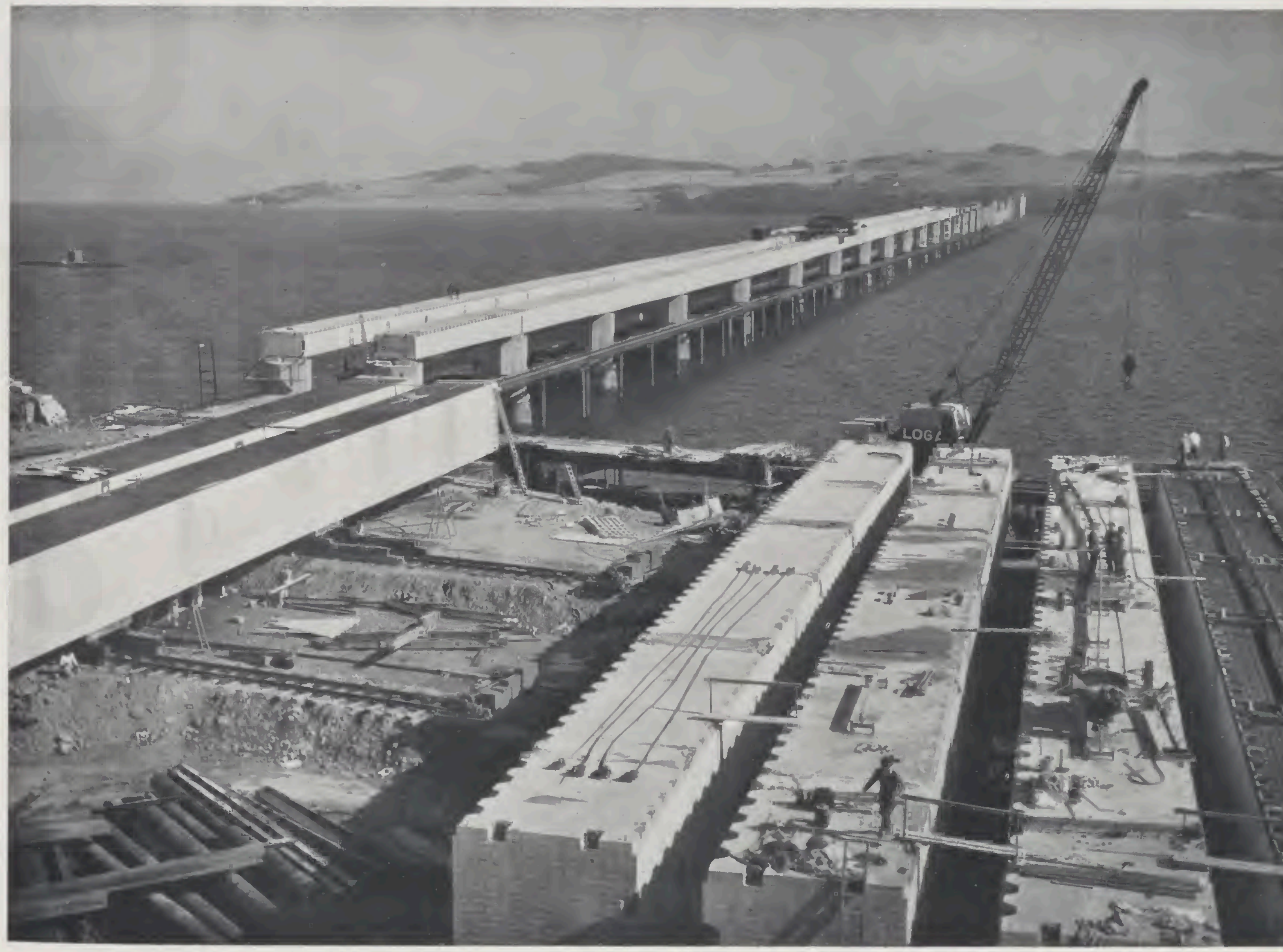


bad weather as even a light wind swung them as they were hoisted into position. Bottom, twin columns on the Fife shore, strong, efficient, elegant as a piece of modern sculpture. If the bridge had been clumsily conceived it could have looked like a jetty. Design of this quality makes it a work of art.





The box girders were built in a Dundee shipyard and delivered in three sections, to be welded together on the site into spans 180 feet long. Note the studs (opposite page) which at a later stage were to provide a secure bond between the steel girders and their concrete upper surfaces. The concrete top and ends of the girders show clearly in the lower photograph on this page. The extreme right-hand girder is having the concrete cast on it.

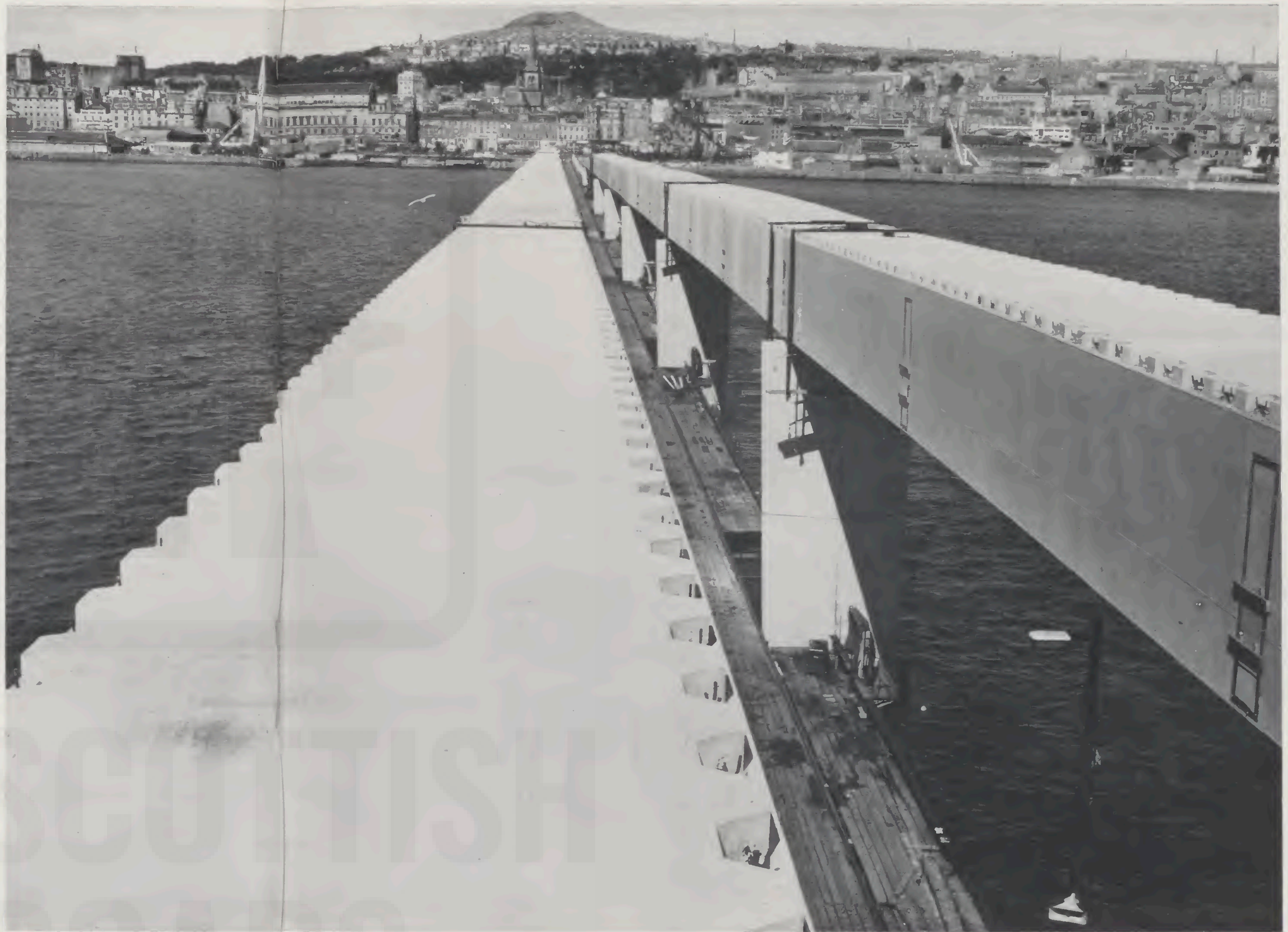


Brought down to human scale, the girders are vast: the painter above reaches less than half way to the roof. To raise them into position, the first step was to fix a temporary lifting platform to the top of the piers, starting (above) with the supporting legs. Right, the platform is in position and the lift begins. Below, opposite page, the spans are supported on stainless steel bearings to allow for expansion and contraction.

The square structures on top of the pillars (below, left of picture) house the jacking equipment. The one on the right has helped to lift a girder into position and is about to move midway between the two piers to lift the next girder. The housing on the left is already in place. Each girder weighs 200 tons.

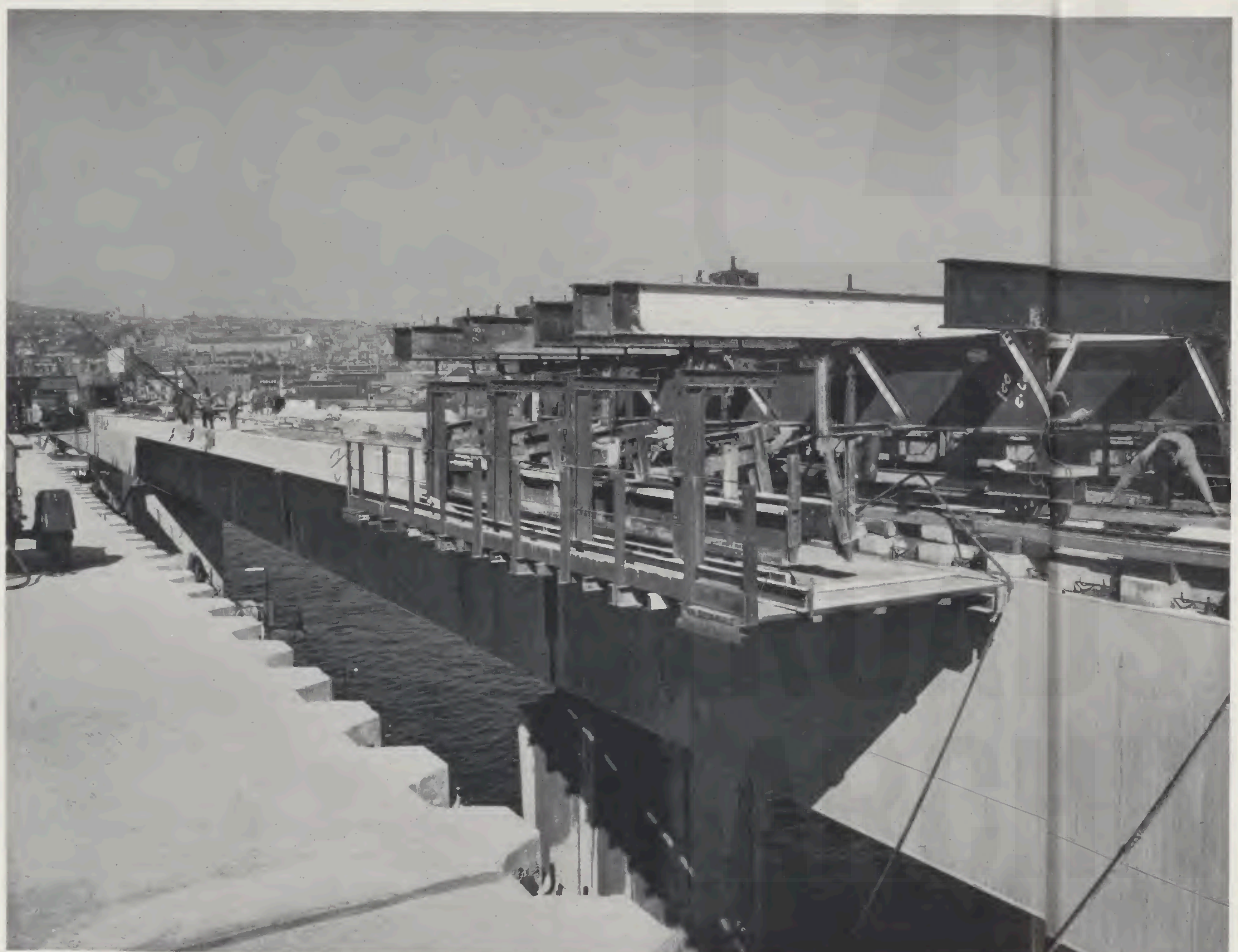
The Tay road bridge is so designed that it stands high above the river at the point near the Fife shore where the navigation channel lies: there is no need for an opening span to allow ships to pass through. During construction, however, the temporary bridge had to open, running as it did low across the river throughout its length. This was provided for by erecting a permanent span over the channel well in advance of the others and hanging an opening bridge from it—a considerable feat of engineering, as the hanging structure had to span a gap of 200 feet and yet open and close without delay.

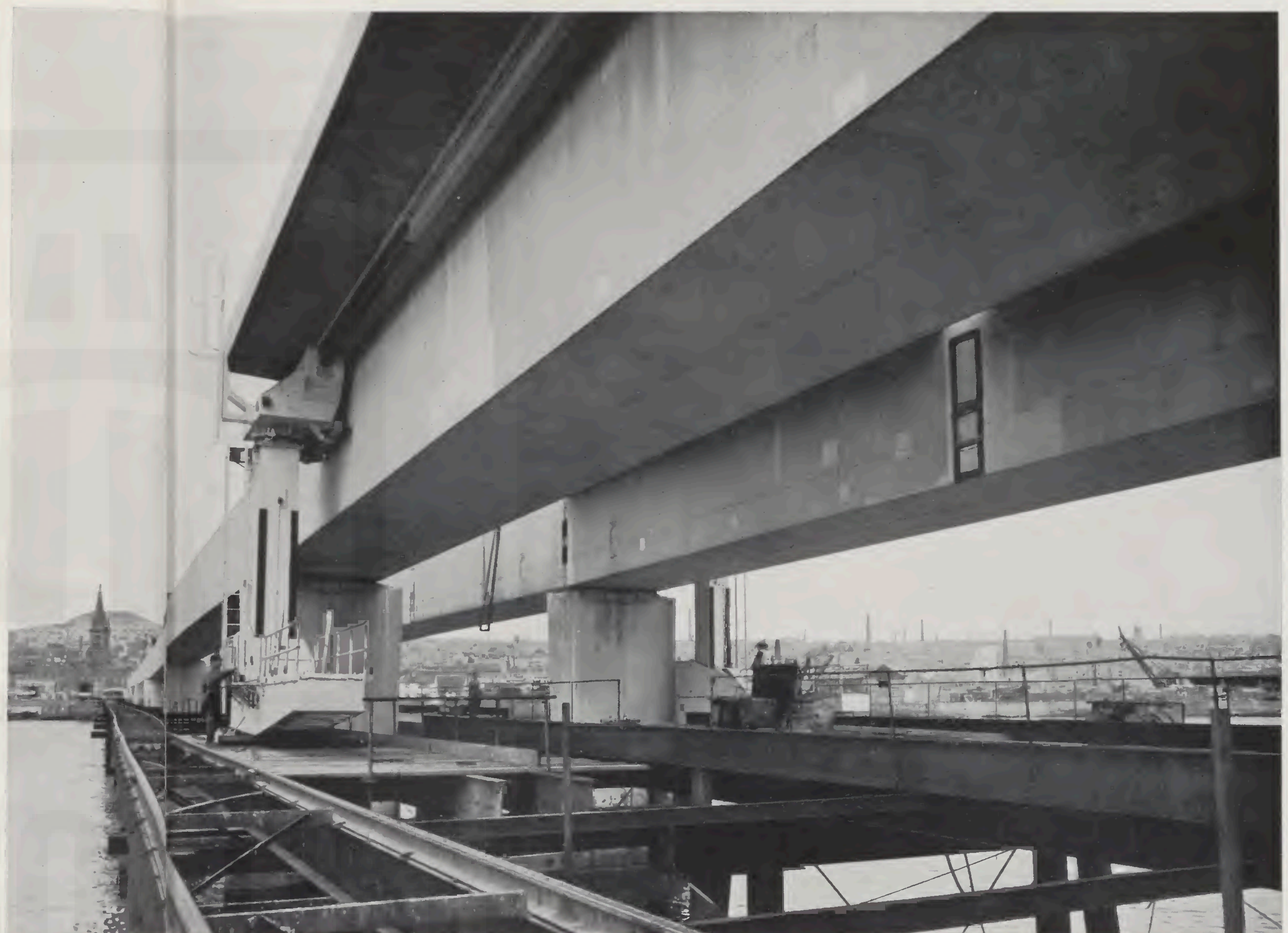
The temporary navigation span had to be substantial: when the permanent bridge had caught up with it, all the heavy box girders, locomotives, cranes and equipment for the subsequent spans had to pass over it. Three stages are shown here—the bridge approaching the opening span, crossing it, and moving on beyond it. The peak on the underside of the box girders marks the navigation channel.



The building sequence continues behind the advancing spans. The first step is to lay a concrete upper surface on those girders not already concreted ashore. Top left, bonding pegs ensure that concrete and steel become one structure combining the special qualities of each material, resistance to compression in concrete, resistance to tension in steel. This arrangement, never before used on so great a scale, allowed materials to be used with maximum economy and was cheaper than all-steel or all-concrete construction would have been.

The next stage—reinforced concrete carriageways are cantilevered out from the box girders, cast a short section at a time in the shuttering shown here. The shuttering, or mould, hangs from steel beams running on rails (below) and moves on as the concrete sets. The overhang of the carriageway, some of it completed, some still in the shuttering, shows clearly in the photograph bottom right.





The completed carriageways leave a narrow gap down the centre of the bridge, which is virtually two parallel bridges with connecting members at intervals. The service ducting, which carries Post Office and electric cables and a high-pressure watermain, is dropped into the gap (opposite, bottom). The curious contrivance hanging from the bridge (opposite, top and bottom) will in future allow the painters to work on the outside of the girders and also reach the doors leading inside them.

A high-pressure main is laid in the duct to carry water from Dundee to Fife: when demand increases the pressure will simply be stepped up. The "lid" of the duct is also the central footpath, with its attractive random paving and aluminium handrails—the first use of aluminium rails on a bridge of this size. The half-completed crash barrier in the background (opposite) is also aluminium. The paving squares were cast and the aluminium fabricated in the far north of Scotland by subsidiary companies of the contractor. Despite the central position of the footpath, pedestrians can if they wish look down on the river: in addition to the Dundee tollbooth platform, a special viewing platform has been cantilevered out over the carriageways near the Fife shore.

The furnishings of the bridge (above and opposite page) have been designed for lightness and elegance. Top left, this page: an early stage in the construction of the Dundee terminal viewing platform. Left, one of the expansion units which is level with the final road surface and allows the spans to contract and expand as the temperature changes. The difference in length, summer and winter, can be as much as $1\frac{1}{4}''$ per span.

3·6 miles of approaches link the bridge to the road system of Fife and include a bridge over the main railway line. Their jumping-off point is the massive Fife buttress. The Dundee approaches (opposite page) are dominated by the terminal system which carries traffic to and from the bridge on raised causeways. The clutter of these construction photographs has largely disappeared and ultimately the area being landscaped will probably surround a number of public buildings.


ASPHALT
SURFACING
BRIGGS

The approaches in Fife are simple and uncomplicated. Traffic is fed by a roundabout (top left, opposite page) on to the road in the background, which leads to a second roundabout (top centre) at the end of the bridge. This road bypasses Newport (top right), and has dual carriageways throughout (above). The Dundee approaches are shown on the left. They pass over the city's main east-west road and deliver traffic on to the ring-road.

DESIGN
The bridge was designed by William A. Fairhurst, C.B.E., assisted by the staff of the firm of W. A. Fairhurst & Partners, Glasgow.

BUILDING
The main contractors were Duncan Logan (Contractors) Ltd., Muir of Ord.
The box girders were fabricated by the Caledon Shipbuilding and Engineering Co. Ltd., Dundee, with Sir William Arrol & Co. Ltd., Glasgow.
These firms were sub-contractors to Dorman Long (Bridge & Engineering) Ltd., Luton, who had the contract for the steelwork, and were responsible for the steelwork erection.
The approach roads on the Fife side were built by A. M. Carmichael Ltd., Edinburgh.
The approach intersection and roads on the Dundee side were built by Duncan Logan (Contractors) Ltd.

THE BOARD
The present members of the Tay Road Bridge Joint Board are
Representing Dundee Corporation
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