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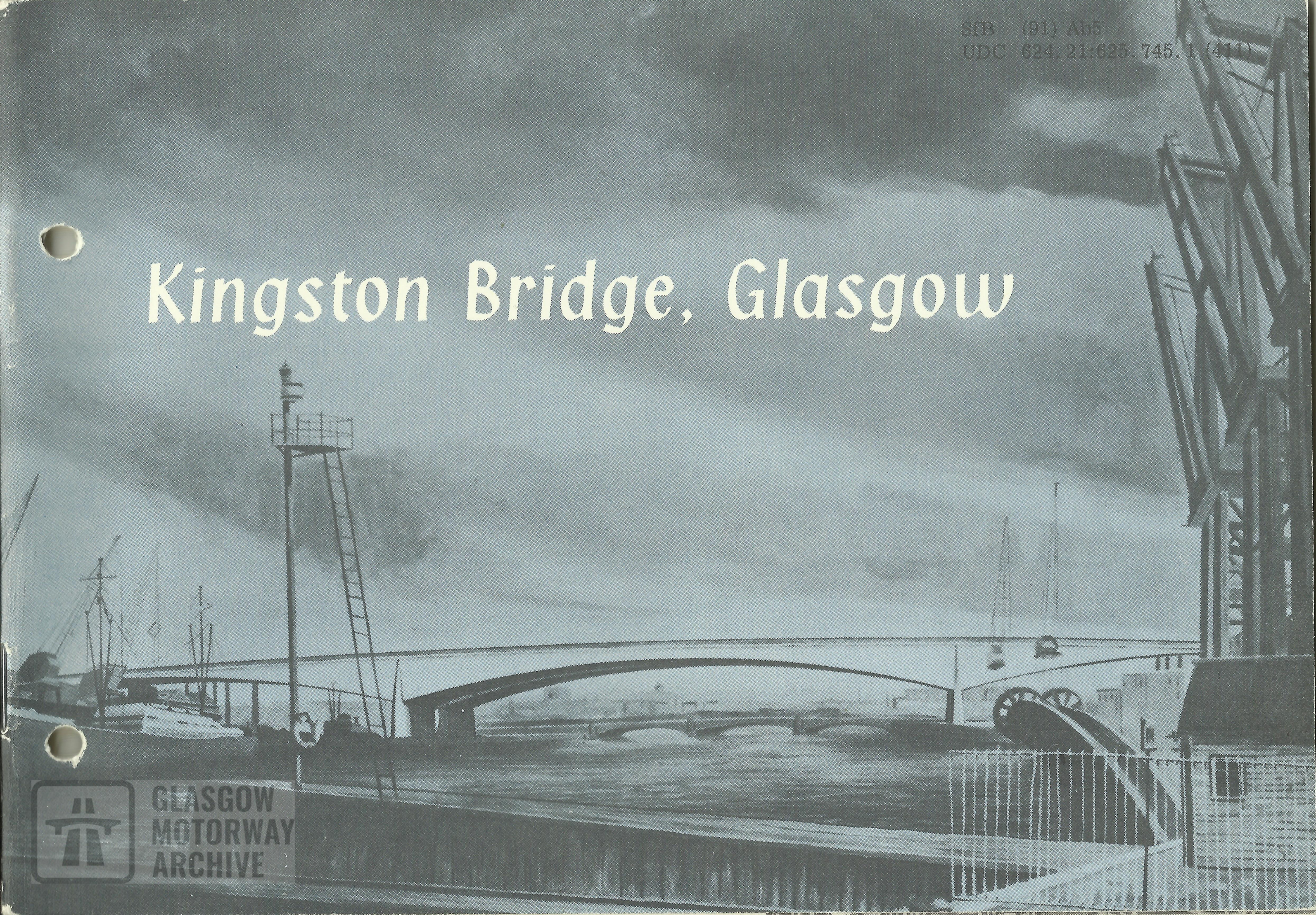
Kingston Bridge, Glasgow



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KINGSTON BRIDGE, GLASGOW

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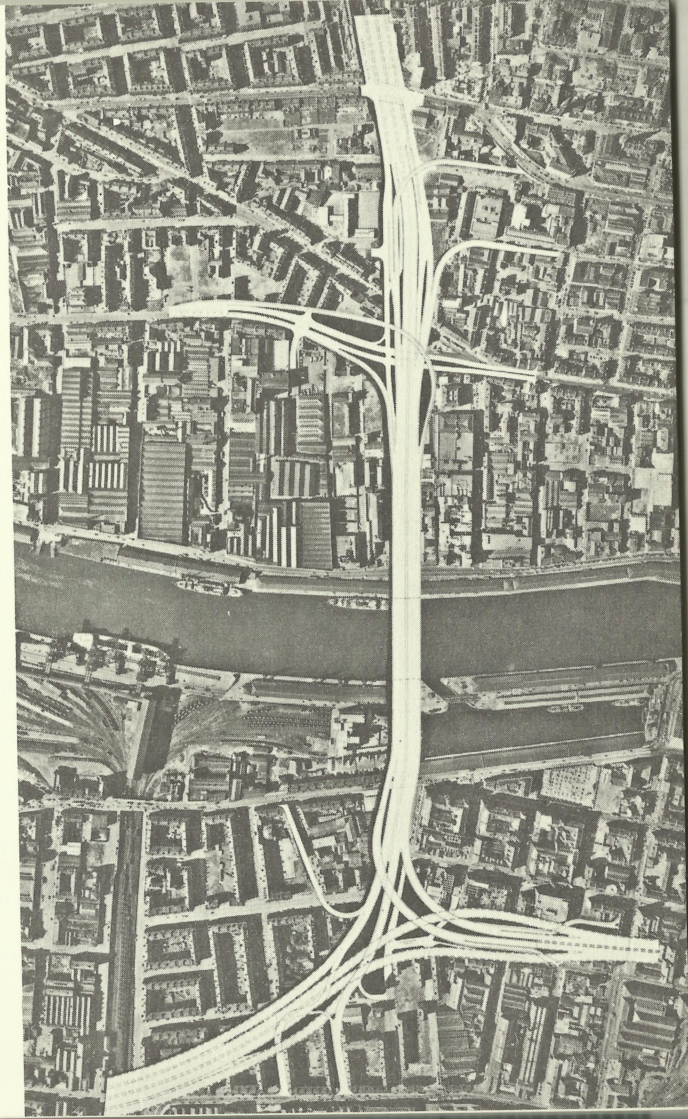


CONTENTS

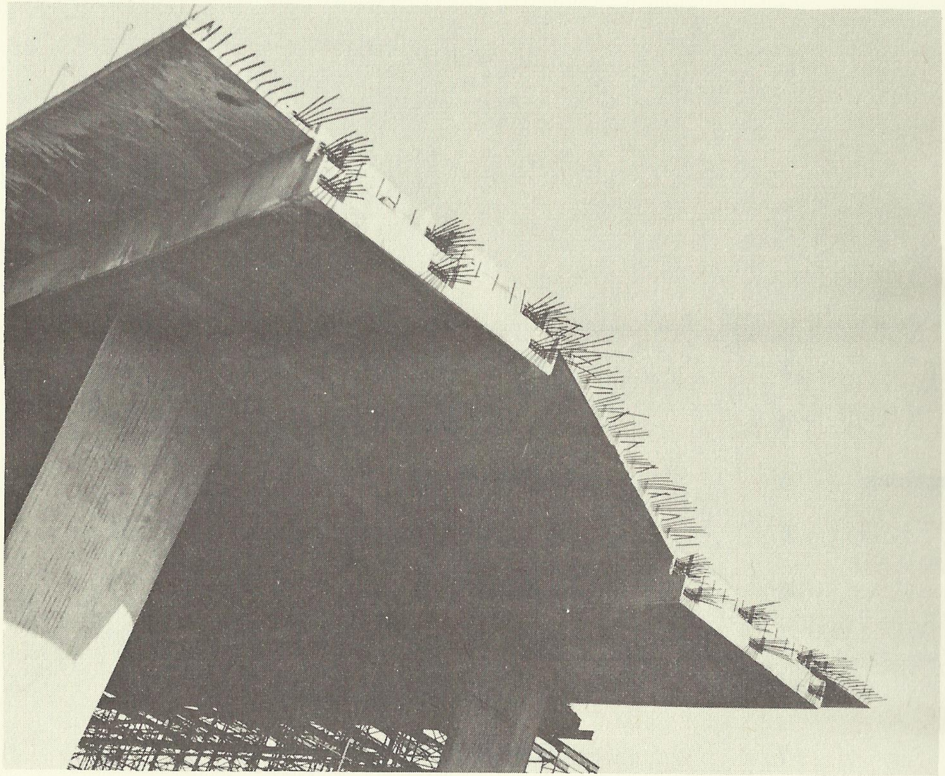


Figure 1: Approach structure cantilever spans. The cantilevers shown are staggered to accommodate a skew road crossing.

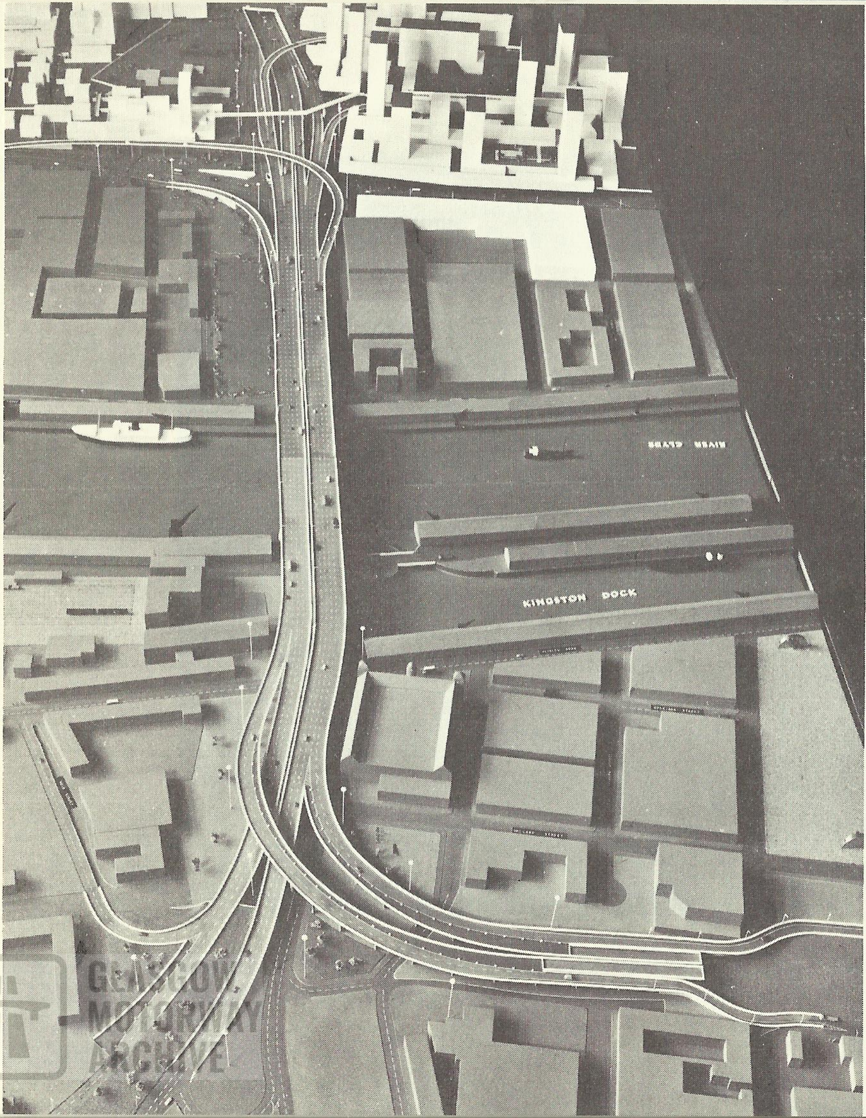


Figure 2: Model of bridge and approaches,
viewed from the southern end.

The main feature of the overall roadway layout are interchanges at Anderston Cross and the south end of the contract, the latter being an intermediate arrangement pending the construction of the South Flank and the Renfrew Motorway. Because of the number of ramp connexions, the width of the approach structures changes almost continually; this, together with variations in longitudinal profile, cross fall and horizontal curvature, was the largest single factor in the choice of in situ concrete for the structural work.

The Kingston Bridge provides over 60 ft clearance to the river navigation channel and the roadway is about 60 ft above ground level at its main piers.

Road design standards

The Inner Ring Road is designed to urban motorway standards with the following main characteristics:

Design speed	main route	50 mph
	interchanges	40 mph
	approach ramps	30 mph
Maximum gradients	main route	4.5%
	ramps	6.5%
Cross fall	normal	2.5%
	maximum superelevation	7.0%
Transition curves	normal length	200 to 250 ft
	minimum length	150 ft

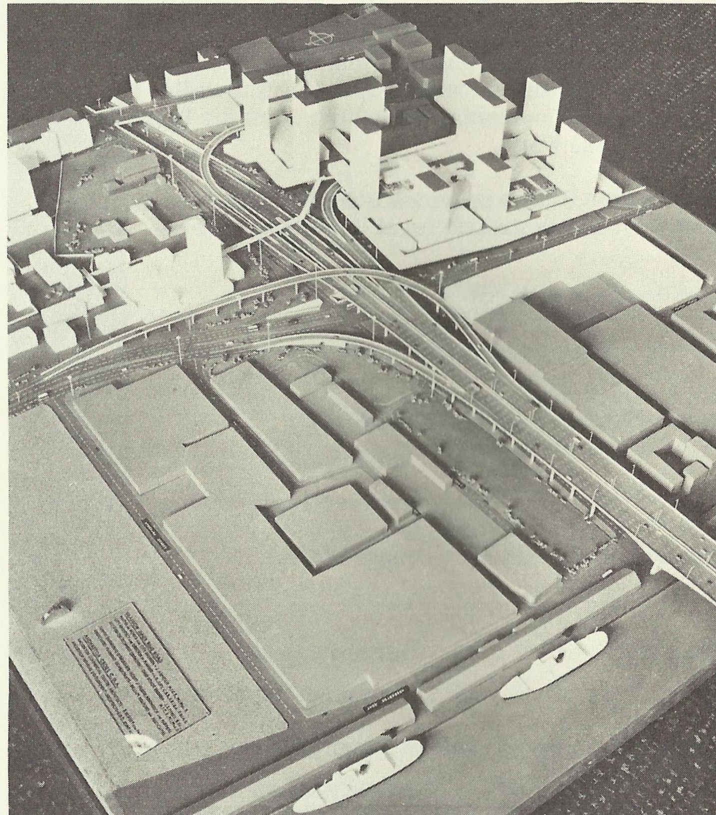


Figure 3: Approach and interchange layout at Anderston Cross (northern) end.

The dual five-lane Kingston Bridge is expected to be carrying 70, 000 vehicles per day by 1975 and over 120, 000 by 1990.

The width of lanes is 12 ft, with an additional 1 ft adjacent to kerbs. For economic reasons, shoulders are not provided except on single lane ramps where there is an extra 6 ft of width.

Site layout and service diversions

The site lies within the Shields Road and Anderston Cross comprehensive development areas. While the new elevated roadway layout is predominantly North-South in character, it is crossed in an East-West direction by five major traffic routes: Paisley Road, Springfield Quay, Anderston Quay, Argyle Street and St Vincent Street; by the River Clyde; and by the Central Station low level railway line (at present suspended from use) under Argyle Street. The construction programme had to make allowance for maintaining the flow of road traffic and for the unrestricted passage of river traffic at all times.

The urban nature of the project demanded a close study of services and involved the relocation of major water, gas, electricity, GPO and drainage services on an extensive scale. The opportunity has also been taken to improve their layout with a view to future requirements. The magnitude of this work may be judged from its cost of over £350, 000 - about 5% of the total contract value. Because of their influence on many aspects of the structural work, however, the actual cost of service diversions will be considerably higher.

In addition to the diversions, a 6 ft diameter storm water drain is being constructed, mainly in tunnel, on the north side of the river, within the contract. This tunnel, which runs from a point near St George's Cross to the river, is almost a mile long and will serve not only the North and West Flanks of the Ring Road but also adjoining present and future developments.

Ground conditions

The site investigation involved the sinking of some forty boreholes. These indicated that sandstone or siltstone was to be found at depths between 120 ft below ground level at the south end of the site and 50 ft at St Vincent Street. As would be expected in what was once a wide river valley, the materials overlying the bedrock are extremely variable. Generally there are great depths of finely graded sands varying from loose to fairly dense, with silt in places. Near the river there are cobbles, boulders and gravel in a matrix of sand or clay immediately above the rock, and the clay content of the soil becomes increasingly pronounced at the extreme north end of the site. The upper 3 ft to 8 ft comprises road paving material and granular upfill, and throughout the site strip foundations and basements of old buildings are always in evidence. Ground water in the boreholes followed tidal variations between depths of 10 and 20 ft below ground level. The sulphate content of the ground water is low and does not require precautions to be taken with foundations.

KINGSTON BRIDGE

Kingston Bridge will provide ten traffic lanes on two parallel independent superstructures each 68 ft wide. The bridge crosses the Clyde by a single central span of 470 ft with a navigation clearance of 60 ft above high water and will have two side spans of 205 ft. Shipping considerations preclude the use of temporary supports in the river so the bridge will be constructed in free cantilever both over the river and to allow free flow of traffic along the quayside roads under the side spans. To ensure stability the side span construction will lead the river span by 10 ft and propping towers will be used at intervals under the side spans.

The design loadings are those of BS 153 but since each carriageway comprises five lanes full HA loading has been extended over three lanes and one third HA loading on each of the other two. The design is capable of sustaining 45 units of HB loading.

Foundations

The riverside quays are founded at river bed level and protected by timber sheet piles with about 25 ft penetration. To avoid the costly disturbance of these walls the bridge piers are founded behind the walls, the pier being about 45 ft back from the quay face. Steel H-section piles were chosen to give the minimum ground disturbance. The section used is 12 in. by 12 in. by 175 lb/ft and is believed to be the heaviest steel pile section used in this country. Driving was carried out very speedily using Muller vibrators and sets proved with a 6 ton single acting steam hammer. The piles have 1 in. thick steel plates welded to their tops and are incorporated in the bottom 2 ft of a 9 ft thick reinforced concrete pile cap 160 ft long and 30 ft wide.

Piers

Each pile cap carried two dozen knuckle pin bearings, each of 1, 000 tons capacity and weighing 2 tons. The reinforced concrete piers are cast in 5 ft lifts over the bearings and are held upright by steel links anchored to the pile cap and cast into the first pier lift. Each pier weighs approximately 2, 000 tons and tapers from 11 ft 9 in. at ground level to 7 ft 6 in. at the girder springing 25 ft above ground. A curved cutwater is formed at each end of each pier and is tapered upwards to an apex a few feet below road level. The south pier is basically two 2 ft thick vertical concrete slabs 3 ft 6 in. apart. These approximate in bending stiffness to a 7 ft 6 in. thick solid pier but offer much less resistance to horizontal movements due to temperature and creep than a solid pier. The north pier is essentially a 25 ft high rocker as it is provided with spheroidal graphite iron bearings at springing level.

Superstructure

Each carriageway is carried by a 53 ft wide three-cell box girder with 7 ft 6 in. deck cantilever slabs. The boxes taper from 35 ft deep at the piers to 8 ft over the middle of the river and to 4 ft 4 in. at the bridge approaches. All webs are 12 in. thick while the bottom flange reduces from 3 ft at the piers to 1 ft at the ends and middle.

The superstructure is of Y$\frac{3}{4}$ concrete to MOT specification giving a cube strength of 6, 000 lb/in^2 at 28 days, prestressed with Macalloy 4/1$\frac{1}{4}$ in. tendons in the top flange and 1/1$\frac{1}{4}$ in. web tendons. As this is the first application of the four-bar tendon in a bridge in this country, three series of tests were carried out in conjunction with McCalls to develop a suitable anchor plate and disposition of reinforcement. The bars will be generally of 30 ft lengths with staggered couplers to facilitate grouting.

The first 30 ft of the land span and the first 20 ft of the river span will be cast on conventional centering to provide an erection platform for the travelling carriages which support the cantilever formwork. Each cantilever section will be 10 ft long and each carriage and set of formwork weigh 264 tons. The cantilever sections will be stressed when the concrete reaches a strength of 5, 000 lb/in^2 and tendons extended or anchored as necessary.

The maximum average compressive stress in a flange is approximately 1, 600 lb/in^2 and no residual tensile stresses are anticipated. The vertical web tendons are proportioned to give a residual compression of around 100 lb/in^2.

The cantilevers in a structure of this magnitude will undergo considerable deflexion at their tips before they meet over the river or reach the end supports. To predetermine this and to enable the formwork to be set correctly for each pour tests are being undertaken at Paisley College of Technology to learn the creep characteristics of the concrete and a programme for calculating deflexions is being written at Nottingham University.

The central 10 ft of the river span will be formed by joining the tips of the concrete cantilevers with steel trusses which will keep the correct juxtaposition until formwork is erected and the final section completed and stressed. The steelwork will be cast in with the concrete and the bridge will then become continuous for live loading.

Finishes

The piers are cast using steel formwork in 5 ft lifts with joints deeply marked both horizontally and vertically. The surface is rubbed down immediately after stripping.

All soffits are formed with transverse boarded formwork and the construction joints at 10 ft intervals are emphasized. The extreme outer webs will be clad with precast concrete facing slabs.

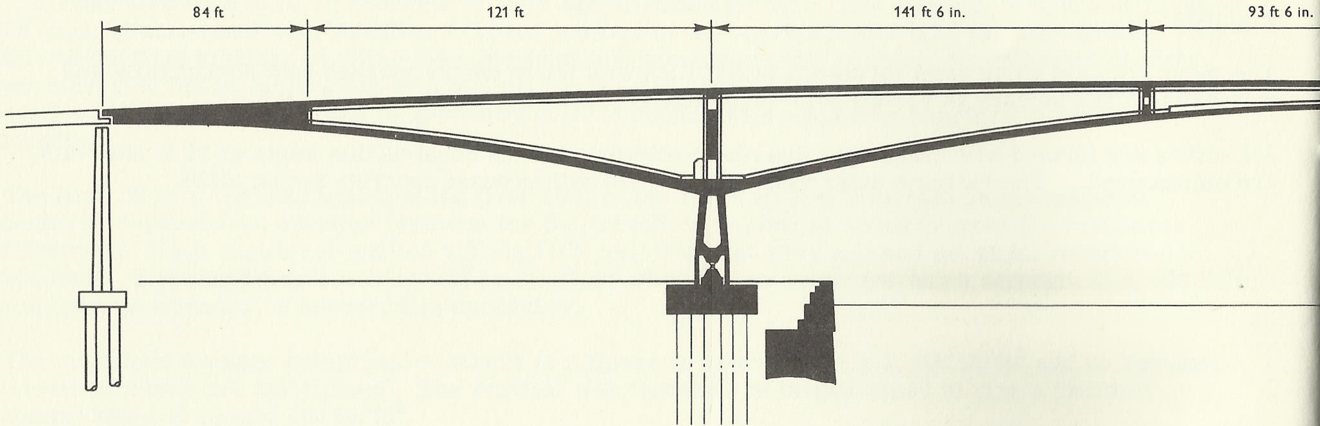
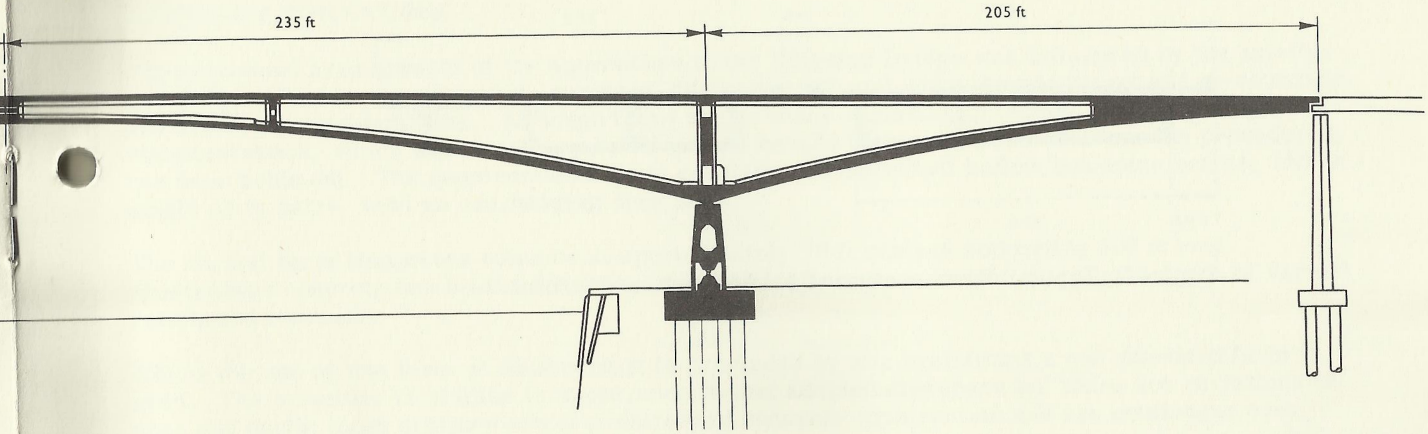


Figure 4: Longitudinal section of main bridge structure.


235 ft
205 ft

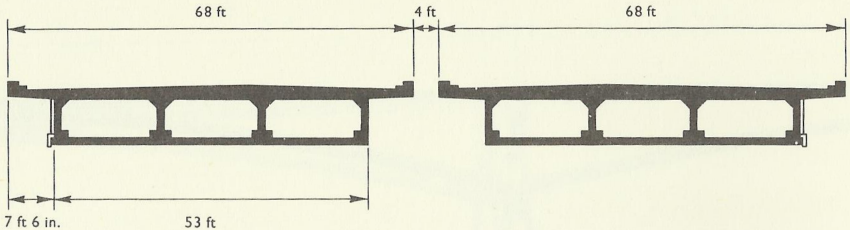


Figure 5: Typical cross-section of bridge deck near crown.

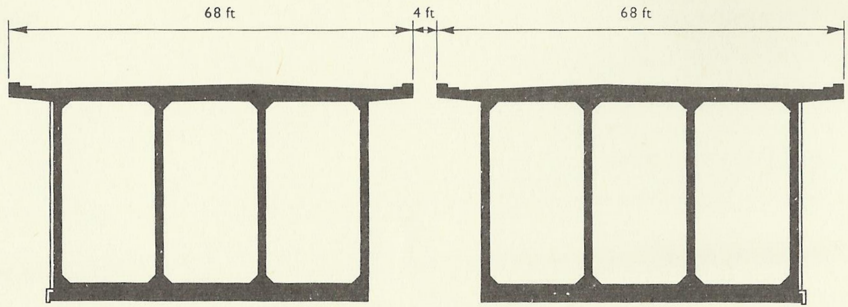


Figure 6: Typical cross-section near springings.

APPROACH STRUCTURES

The structural arrangement of the approaches to the Kingston Bridge was influenced by the existing and proposed surface road layout, services, the railway tunnel under Argyle Street and by economic and aesthetic considerations. Although there are so many variables in the layout, a high degree of standardization, which was necessary to obtain full benefit from repetitive construction procedures, has been achieved. The constructional form consists of longitudinal hollow box spine beams, either singly or in pairs, with an overhanging deck slab.

The normal form comprises columns at approximately 70 ft centres supporting 100 ft long prestressed concrete box beams 4 ft 3 in. deep which alternate with 40 ft suspended spans of normal reinforced concrete.

Where the use of this form of construction is precluded by site limitations a non-standard form is used. The structure is similar in appearance to that adopted elsewhere but there are variations in span and depth; these sections are of prestressed concrete construction and are continuous over three or four spans.

Foundations and columns

All elevated structures are supported on piled bases. Piles are designed to withstand 100 tons of vertical load which is transmitted from the columns, in direct load and bending, through reinforced concrete pile caps 3 ft 6 in. thick. Two types of piles have been used, West's 21 in. diameter shell piles where a suitable bearing could be found in dense sand, and steel H piles of 12 in. by 12 in. by 83 lb/ft section driven to bedrock foundation elsewhere and under all continuous structures. A minimum of 150 tons kentledge was used in all loading tests.

It was realized at the early planning stage that the overall appearance of the project could be considerably enhanced or marred by the columns; there are over one hundred on each side of the

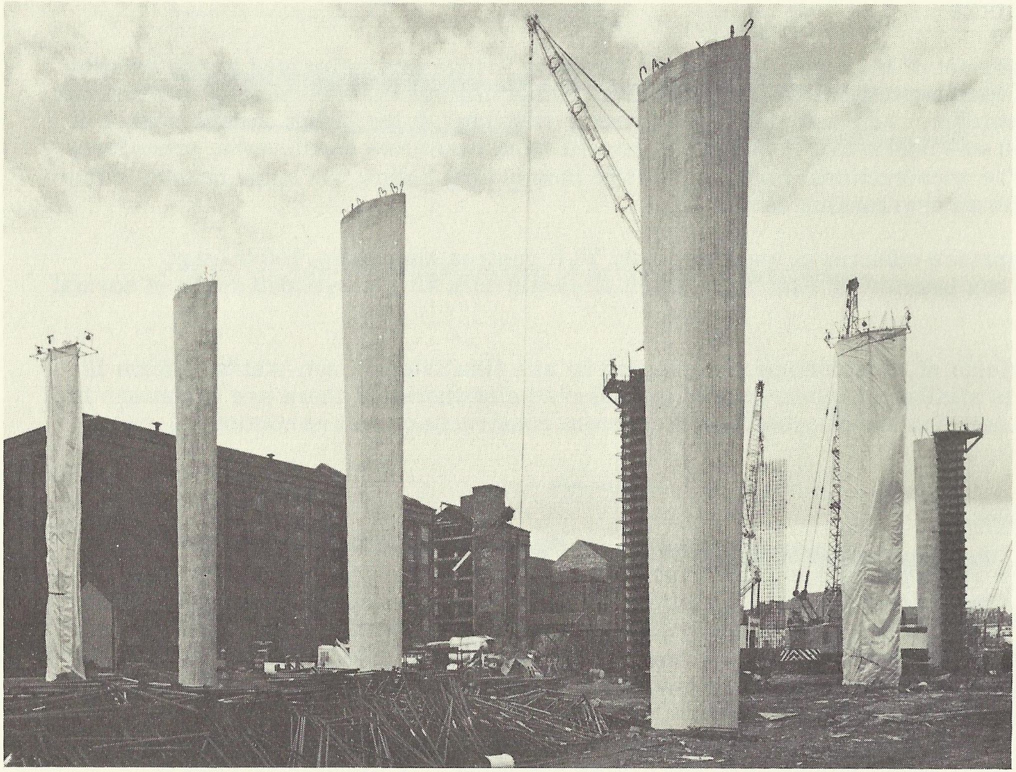


Figure 7: Approach structure columns under construction.

river. Numerous shapes were tried over a period of many months by means of sketch drawings and models. Because of the number of columns involved, costs could be kept low if the shape lent itself to many re-uses of the same formwork. The column had to be wide at the top to give a bearing to the box beams and wide enough in the longitudinal direction at the base to resist bending moments. The shape which was finally chosen comprises twin parabolas at the top and twin cubic parabolas at a level 80 ft below the top, the main axes of the latter being disposed at right angles to those at the top. The perimeter is almost constant throughout the height - an essention prerequisite of the formwork detail. The formwork is made up of half sections bolted together, each formed of steel yokes with vertical boards approximately 2 in. wide. The top section is kept constant, with variations in height obtained by casting the tallest columns first and reducing the length of formwork 2 ft at a time by cutting from the bottom. The columns are cast in one continuous operation at a rate of about 5 yd^3 per hour. The reinforcement was designed to permit the use of a vertical trunk for concrete placing and normal poker vibrators within the formwork. Stripping takes place after 24 hours and the concrete is cured using a heavy duty polythene shroud. Vertical drainage and other service pipes are located within the columns.

Columns are fixed at the bases and pinned at the top and, are designed to withstand both vertical load and bending moments in two directions. The latter are mainly due to braking and wind loading, shrinkage, temperature and elastic movements of the superstructure, and eccentric live loadings. Bursting stresses at the tops of the columns are resisted by mats of closely spaced reinforcement.

Superstructure

All structures are designed for BS 153 loading with the exception that, on the wider decks, a minimum of three lanes are considered to be loaded with HA loading. The effects of 45 units of HB loading were particularly critical on dual and single lane ramps.

Cantilevered spans are generally about 100 ft in length, and are simply supported on columns at about 70 ft centres. The cantilevers, in turn, support 40 ft long suspended spans. They are designed for

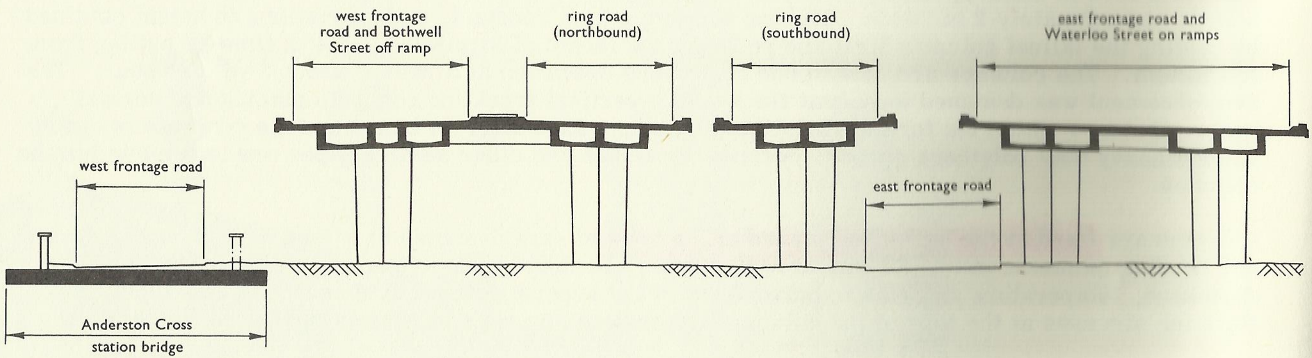


Figure 8: Typical cross-section of approaches, Anderston Cross.

bending, torsion and shear as longitudinal beams using an appropriate width of deck slab as a top flange. The C.C.L. Strand-force system of prestressing has been adopted. This system uses 0.7 in. diameter stabilized strand with a guaranteed breaking load of 83,000 lb, in tendons of five or ten strands placed in a $4\frac{1}{2}$ in. by 1 in. flat duct. With strands being stressed to 70% of their ultimate strength, the design force in a 10/0.7 in. tendon is 260 tons. Sections of deck are stressed when the concrete compression strength has reached 5,000 lb/in^2.

Suspended spans are designed as simply supported longitudinal beams in normal reinforced concrete.

The span by span sequence of construction of the continuous-span structures is of prime importance in the analysis, and consequently the sequence was determined at the design stage. Each structure is designed as a continuous beam. After the first span has been built and stressed from both ends, successive spans are built and stressed back to it from one end only through couplers. The C.C.L. Strand-force prestressing system was also adopted here. The structures are arranged in groups to ensure that longitudinal forces are spread between a sufficient number of columns, and expansion joints are positioned accordingly.

Where ramps approach ground level, the elevated structures terminate at piled abutments. The roadway is then generally carried on a cellular box with a continuous support and finally onto fill between retaining walls. The maximum bearing pressure under these structures is about 1 tons/ft^2 under the most adverse loading.

On dual and single lane ramps, where it is difficult to cater for longitudinal forces on a limited number of columns and temperature effects on low-height columns are considerable, sections have been linked together by means of hydraulic dampers. These dampers are designed to transmit 'instantaneous' braking forces across a gap, but because of the action of pistons against oil pressure they will not impede slowly arising movements due to temperature. The damper units are self contained and are housed within the box beam structure.

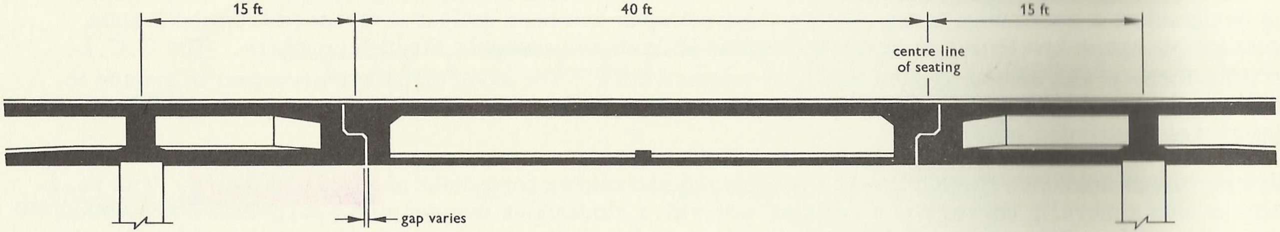


Figure 9: Typical longitudinal section, approach road cantilever and suspended span construction.

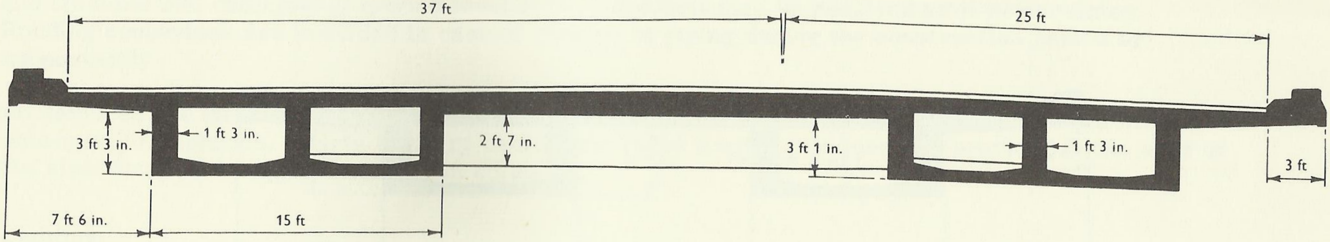


Figure 10: Typical cross-section, five-lane elevated road superstructure.

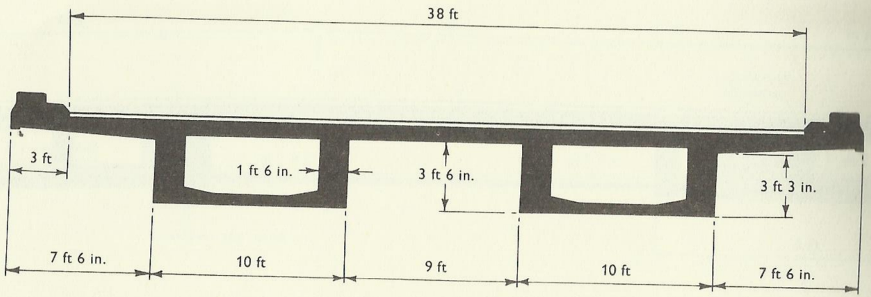


Figure 11: Typical cross-section, three-lane elevated road superstructure.

The cantilevered and continuous spans are continually staged using PAL scaffolding or Acrow props, the load being spread on the ground through sleepers. The suspended spans are built by suspending a grillage of beams by Macalloy bars from the ends of the cantilevers. Soffit formwork is formed in large panels, generally of 2 in. thick boarding, and these are suspended from the completed deck and lowered to the ground after removal of the staging. As much as possible of the reinforcement is being prefabricated in cages.

Drainage and services

The structures are drained through shallow gulleys which discharge through PVC piping in the deck and columns into catchpits at ground level from which grit may be removed as it accumulates. Rodding connexions are provided in case of choking of piping during the construction period or subsequently.

No services are carried on the elevated structures except those required for lighting, road heating and emergency telephones. Ducts to carry cabling for these limited services are provided in the edge of the structures with supply facilities in columns.

Lighting

Most of the lighting to the elevated structures is obtained from 100 ft high masts, each of which supports four 1, 000 watt lanterns. Where it is uneconomical to provide lighting to the elevated structures in this way, conventional 40 ft or 25 ft lighting columns are provided on the edge of the deck. The high masts were erected and in use early in the contract, and were used during the winter of 1967-68 to extend the working hours.

Ramp heating

Where road gradients exceed 5% ramp heating is provided. The loading averages 15 watts per square foot of surface.

Surfacing and finishes

Hot-rolled asphalt surfacing is being laid in two layers each of $1\frac{1}{2}$ in. thickness; shoulders are being defined by coating them with red 'Schlamme' paste.

To ensure uniformity of line, and to obtain the necessary quality of finish which such a project in the centre of a large city demands, precast edge units are being used with a dark aggregate to minimize the effects of staining. The edging consists of a sill unit on top of a cavity block which contains an in situ longitudinal deck edge stiffening member.

OTHER WORKS

Considerable lengths of new surface roads are being constructed within the contract. These include a new dual carriageway running North-South, partly under the elevated motorway, from Anderston Quay to St Vincent Street, and the first 2, 000 ft of the Clydeside Expressway at Anderston Cross.

Three new road bridges and two footbridges form an essential part of the contract. Precast, prestressed concrete deck units are being used at the Bishop Street Bridge while reinforced concrete slab bridges are being built across the railway station at Anderston Cross and across the future extension of the motorway, on the line of St Vincent Street. The latter bridge has been included in this contract to reduce difficulties in dealing with traffic while the Charing Cross section of the Ring Road is under construction. The two footbridges, built in prestressed concrete, will link the new housing and commercial development at Anderston. One of the footbridges is over 400 ft long excluding its helical approach ramp.

LANDSCAPING

Particular care has been taken in the detailing of the structures and in construction to ensure that finishes will be of the highest possible quality. The final appearance of the scheme will be further enhanced by the landscaping of the whole area. Where possible a semi-parkland setting will be produced by planting grass, trees and bushes. In shaded areas under the elevated roadway paving will be used and some of these areas will be used for parking. The high lighting mast arrangement will ensure that 'street furniture' is reduced to a minimum.

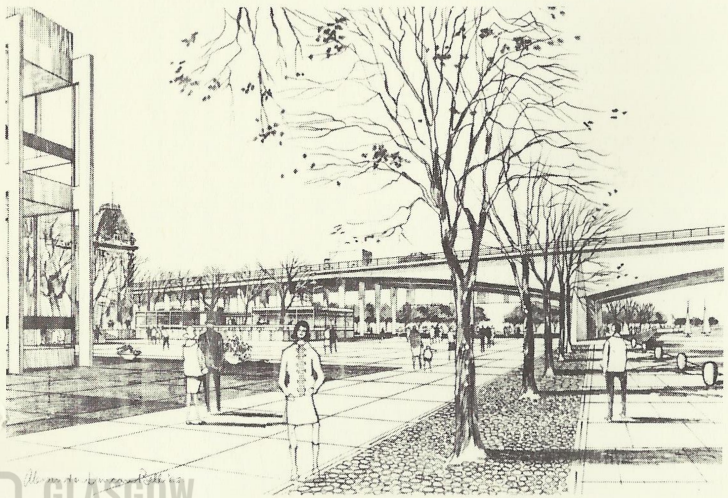


Figure 12: Proposed landscaping treatment.