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The new Howrah Bridge, Calcutta

Die neue Howrah-Brücke in Calcutta

Le nouveau pont de Howrah à Calcutta

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The new bridge, described in this paper and illustrated in Fig. 1, was opened in February 1943 when it replaced the old floating bridge. The latter, which was designed by the late Sir Bradford Leslie K.C.I.E., M.I.C.E. and was opened to traffic in 1874, consisted of 13 spans, the centre one of which was designed to be floated out to permit the passage of large vessels. This caused serious interruptions to traffic over the bridge as can be seen from Fig. 2.

The construction of a new bridge was a matter of considerable investigation over many years, and many types of structure were considered. In 1920 an expert technical committee investigated the problem and reported that the bridge should be of such a type as not to subject the foundations, in the deltaic soil of the River Hooghly, to primary horizontal forces, such as the thrust of an arch or the pull of a suspension bridge. They finally recommended that a cantilever bridge was the most suitable type, and the design finally adopted conformed to this recommendation.

Increases in the volume and weight of traffic beyond the capacity of the bridge, together with structural deterioration beyond the limits of economical maintenance, rendered the replacement of the whole bridge imperative and the Government of Bengal accordingly decided in 1933 upon the construction of the cantilever bridge described in this paper.

The new Bridge

The new bridge, which has a span of 1,500 feet, centres of main piers, provides accommodation for eight lines of vehicles and two 15 feet footways for pedestrians. The bridge deck, which covers the river span between the main piers only, is suspended below the main trusses. The anchor arms do

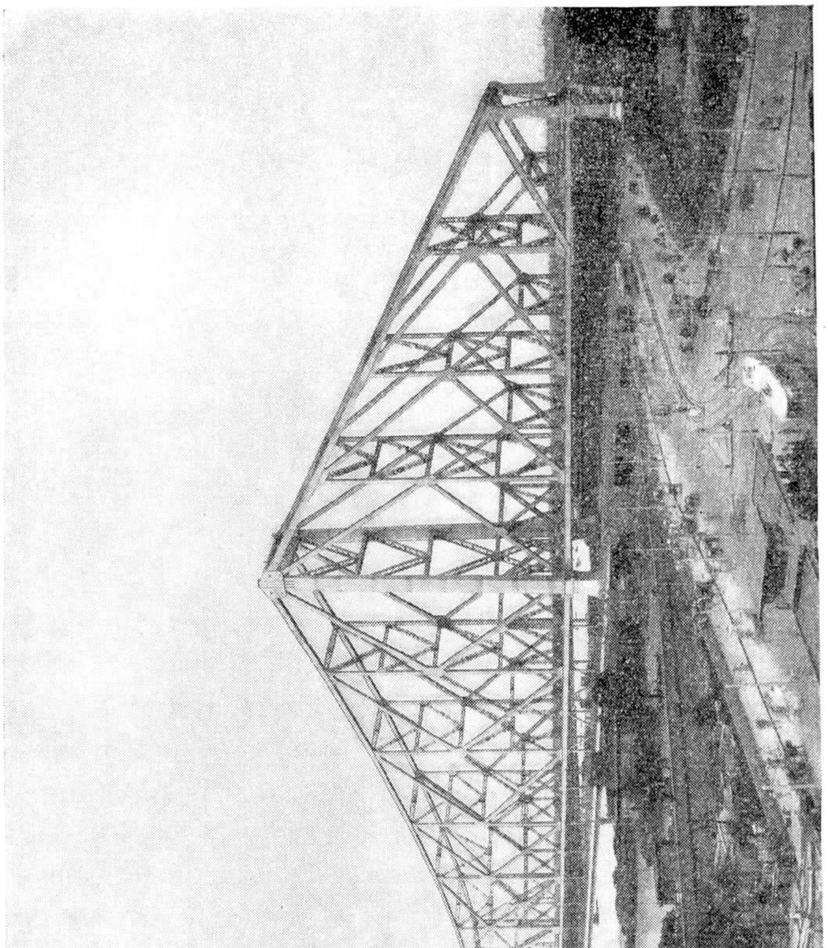

Fig. 1. The New Howrah Bridge

not support the approach roads, which are independent of the superstructure and are carried on reinforced concrete structures founded directly in the ground.

The two halves of the suspended span, which covers the central 564 feet of the river span, were erected as temporary extensions of the cantilever arms until they met. They were then joined together and converted into a simply supported span.

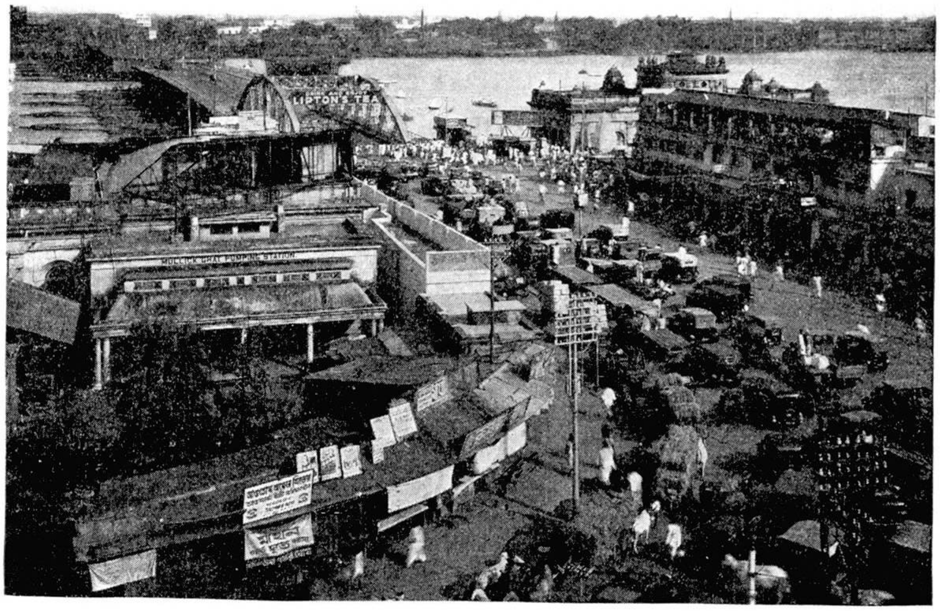

Fig. 2. The Old Howrah Bridge showing traffic hold-up on Calcutta Approach during passage of early morning river traffic.

The two main piers, each consist of a large reinforced-concrete cellular monolith, whilst the anchorages each consist of two small monoliths of similar construction.

Foundations

Main Piers

The two main pier monoliths are each 181' 6" long by 81' 6" wide and each contain 21 dredging shafts, each 20' 6" square. This arrangement provides a sufficient number of dredging shafts to give effective control along the major and minor axes, whilst providing ample weight in the monolith shell, during sinking, to overcome skin friction and cutting-edge resistance.

Anchorages

The anchorages each consist of two separately sunk monoliths, each 27 feet by 54 feet with two dredging shafts and finally connected together by means of a tie-beam.

Design of Monoliths

The monoliths were designed for construction in reinforced-concrete with a structural steel curb and cutting-edge. The upper edge of the curb was designed to accommodate steel shutters which would be moved upwards, in stages, for the construction of further lifts of the reinforced-concrete shell as sinking proceeded.

The main pier monolith caps were designed with reinforced-concrete grillage beams under each of the main tower posts in order to ensure a satisfactory distribution of the load from the superstructure.

Steel Curbs

Consideration of the structural design of the main pier monoliths showed that the critical period for stresses and strains would be during the early stages of sinking, when irregular support of the cutting edges, due to variations in the soil and to unequal excavation in the numerous shafts, would produce bending stresses in the partially constructed monolith shell. As construction proceeded the moment of resistance to bending would increase more rapidly than the bending moment.

As precautionary measures, local inequalities in the upper layer of soil could be ascertained before the erection of the curb was commenced, buried local obstructions near the surface could be located and if necessary removed whilst excavation within the various shafts could be suitably regulated.

Notwithstanding all such precautions, however, some bending and racking stresses would be inevitable, and a maximum variation of 2 to 1 between the cutting edge resistance at the ends of the monolith and at the centre or vice versa was therefore adopted as a basic design criterion for the curbs.

The main pier curbs were designed to be erected complete on prepared level ground and filled with concrete suitably reinforced to form a composite girder of the requisite strength for the afore-mentioned loading condition, before sinking was to be commenced.

The curbs for both the main pier and anchorage monoliths were designed to accommodate temporary airtight diaphragms which could be inserted in any of the shafts, at any time, thereby converting them into compressed air working chambers for the removal of any local obstruction which might be encountered below water-level, or for cleaning out the bases of the shafts and depositing the concrete plugs in the dry. The diaphragms were secured in place by means of latches which were designed for under-water operation by divers and Fig. 3 shows one of the diaphragms assembled complete in the contractors works.

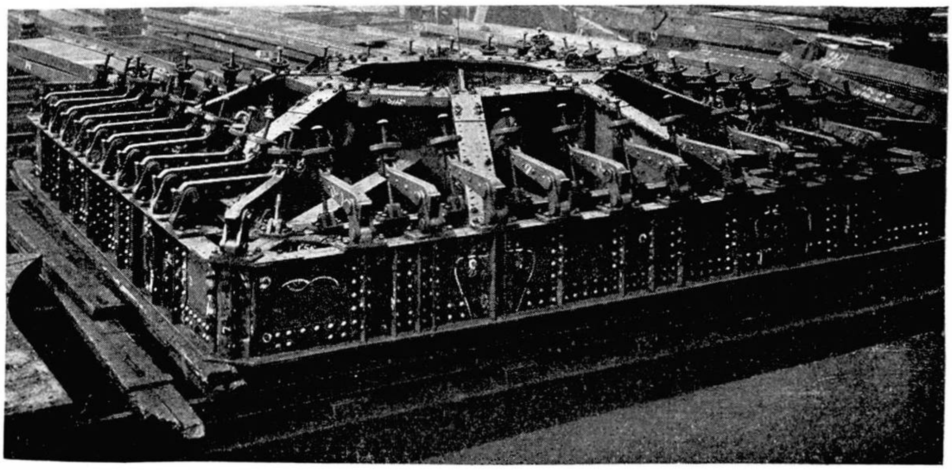

Fig. 3. Temporary air-tight diaphragms for use on main pier monoliths

Proposed Founding Depths

The material on the Howrah side is virgin deposit and generally soft until sand is reached about 60 ft. below ground surface. After passing through about 19 feet of water-bearing sand, a bed of stiff clay is reached. On the Calcutta side, material above the clay is of comparatively recent deposit, because at one time the course of the deep channel of the river followed the Calcutta bank. Above the stiff clay, which is found at about R.L.-72,00 or about 97 feet below ground surface, the deposit is generally silver sand and grey silt which is water bearing.

The proposed founding depth on the Howrah side was fixed at R.L.-60,00 or about 8 feet into the stiff clay, and experience gained when sinking a trial cylinder indicated that it might be possible to lay the foundation in the open. On the Calcutta side, the proposed founding depth was fixed at R.L. -88,5, but owing to a stratum of water-bearings and at about R.L.-103,00, it was anticipated that compressed air would have to be applied to enable the concrete plugs to be laid in the dry. Both these expectations subsequently proved to be correct, and the Howrah and Calcutta Main Pier monoliths were ultimately founded at R.L.-62,5 and R.L.-79,13 respectively.

Sinking of Monoliths

Previous experience on the sinking of trial wells for King Georges' Dock and of trial cylinders at the Howrah Bridge site, showed that it should be possible to sink the main pier monoliths into the stiff clay by open dredging.

The specified method of sinking was therefore by hand excavation until the depth of penetration rendered this method uneconomical or until standing water level rendered it impracticable, and thereafter by grab excavation.

Both of the main monoliths and one pair of anchor monoliths were sunk to full depth by open dredging. The other pair of anchor monoliths — those on the Calcutta side — ran into a thick bed of fine sand and, as one of them was very close to the main office building, the Resident Engineer decided that dredging should be discontinued and pneumatic sinking commenced.

The Howrah monoliths were sunk through more or less impervious materials, ranging from a soft spongy consistency near the surface to a stiff yellow clay at founding-level, 87 feet below ground-level. A good penetration (about 7 feet into the stiff clay) was obtained and all the shafts were plugged in the open, after individual de-watering, with about 15 feet of back-filling in adjacent shafts.

On the Calcutta side, soon after sinking was commenced, parts of old "country boats" and their cargoes — mainly bundles of flat and round iron bar — which had become embedded in very soft mud and silt, were dredged up from all shafts of the main monolith. This did not delay progress as much as might be expected; the weight of the monolith and of the heavy grabs broke up the obstructions quite effectively without the assistance of divers or explosives.

At 50 feet below ground-level the Calcutta main monolith entered a fine compact sand bed 30 feet thick, through which progress was excellent. The monolith was finally founded at 103 feet below ground-level after it had penetrated 6 feet into the blue clay.

All monoliths were constantly kept under careful observation for level and position. Any tendency to run off plumb was dealt with almost before it had started. Accuracy of sinking left nothing to be desired, the biggest departure from drawing position of the top or bottom of any monolith in either direction being only 2 or 3 inches.

Bearing Pressures

The loads per square foot on the bases of the complete main pier monoliths, including water in the cells to datum level are, Howrah Main Pier 3.95 tons per sq. ft. and Calcutta Main Pier 4.66 tons per sq. ft. In each case these figures are approximately equal to the existing pressures at the founding levels.

To the above figures must be added a pressure of 1.52 tons per sq. ft. due to the dead load of the superstructure, whilst the specified normal live load on the bridge would be responsible for a further pressure of 0.26 tons per sq. ft.

Assuming the monoliths to be filled with water up to datum level, the gross loads at the founding levels are therefore 5.73 tons per sq. ft. and 6.44 tons per sq. ft. for the Howrah and Calcutta Main Piers respectively.

The "active" pressure on which settlement calculations were based, was taken as 1.8 tons per sq. ft. which is approx. equal to the Dead Normal Live Load reaction of the superstructure.

Superstructure

Principal Characteristics

The river span of 1500 feet centres of main piers is made up of two cantilever arms, each 468 feet long, and a suspended span of 564 feet. The anchor arms are each 325 feet long. The main trusses are spaced at 76 feet centres and the road is 71 feet wide between kerbs.

The superstructure is located both longitudinally and laterally by two vertical pins on the central axis of the bridge, one at each main tower. Longitudinal freedom to respond to changes of temperature is provided by expansion joints between each cantilever arm and the suspended span. The lateral wind reactions at the ends of the anchor arms are taken by wind frames situated on the anchorages. The main posts of the towers are sufficiently flexible to accomodate the elastic deformation of the structure in the plane of the bridge.

Suspenders for the deck are provided at all main and subpanel points throughout the 1,500 feet of the main span. No upper lateral system is provided on the cantilever and anchor arms, the upper chords of which are permanently in tension, but complete sway frames are provided at all main and sub-verticals, and also a complete lower lateral system. Complete upper and lower lateral systems, and sway frames at all main verticals, are provided on the suspended span.

Influence of Erection on Design

The erection of a structure such as new Howrah Bridge has a major effect on the detail design. Consideration was given to the erection of the suspended span by cantilevering out or, alternatively, by floating out and hoisting into place, as on the Quebec bridge. Investigation showed that, as creeper cranes would be required for the erection of the anchor and cantilever arms, the former method would be economical, the only permanent members which required strengthening to accommodate the erection stresses being the upper and lower chord members between the cantilever arms and the suspended span. A major problem in connection with the creeper cranes was the transferring of the crane from the upward slope of the anchor arms over the tops of the towers and on to the downward slope of the cantilever arms.

The Contractor met this problem by using separate cradles to which the cranes were secured whilst travelling up the anchor arms and which were left behind when the cranes moved forward, on their own undercarriages, on to the cantilever arms.

The arrangement of the cranes and cradle can be seen in Fig. 4, which shows the erection of the Howrah Anchor Arm nearing completion.

Towers and Main Bearings

The two main towers each consist of two posts, with a system of K-bracing between them and a portal opening at decklevel through which the road traffic passes. The posts are spaced at 76 feet centres at the tops, that is the same as the main trusses, but are splayed out to 95 ft. 8 ins. centres at the pier cap level in order to allow the lower chords of the trusses to pass between them.

The main bearings are of the sliding type and are inserted between the lower chords of the cantilever and anchor arms, with pin connections to these members and to the main truss diagonals. They are of forged steel slab construction, suitably diaphragmed and fitted with rolled manganese bronze bearing plates, and are supported on pedestal extensions built out from the main posts. This arrangement is shown in Fig. 5 which also shows the suspended deck as viewed through one of the Main Towers.

The posts are of rectangular cross-section and the lower portions are widened out to incorporate a series of grillage girders, forming a base approximately 24 feet square.

Wind Frames at Anchorages

The wind frames at the anchorages are situated on the central axis of the bridge and are designed to take the lateral wind reaction of the superstructure, without interfering with the longitudinal and vertical movements resulting from changes in length of the superstructure and the anchor links caused by variations in temperature and stress.

Each frame consists of a pair of braced A-frames, between the apexes of which passes the end lower lateral cross-strut of the anchor arm, and is fitted with a vertical pin carrying a rectangular casting with machined faces in sliding contact with manganese-bronze bearing plates mounted in the end transverse member of the superstructure.

Provisions for Adjustments at Anchorages

Provision is made for adjustment, during erection and at any time during the life of the bridge, of the levels of the noses of the cantilever arms, and thereby of the suspended span, should the settlement of the main piers be such as to render this necessary.

Each anchor girder accomodates eight sets of packings (four on each side of the pin connection), thus providing twenty-four packing-points per set of girders. Intermediate diaphragms are fitted between the girders to accommodate sixteen hydraulic jacks per set, for pulling down the anchor links in order to adjust the total thickness of packings at any point.

Each set of packings consists of a number of removable parallel packings of graduated thicknesses, to enable the total thickness to be adjusted in multiples of $\frac{1}{8}$ inch. Each set also contains an adjustable packing with a taper of 1 in 100 for micrometer adjustments.

In order to ensure proper distribution of load between the various packing-points, the stages of erection at which the various packings should come into operation were calculated. The theoretical gaps at each given stage of the work were checked as the work proceeded and the next set of packings, if they had not already contacted, were tapped into contact at the appropriate stage.

In this way the required distribution of load, and thereby of the design stresses in the anchor girders, was theoretically assured. In actual practice some initial adjustments of packing thicknesses were necessary to suit the actual setting of the girders, but there was no subsequent need to bring the jacks into operation to effect the required distribution of load.

Bridge Deck

The roadway has a clear width of 71 feet between kerbs and the total width of the deck is 108 feet 9 inches between centres of fascia girders at the outer edges of the two cantilevered footways. Deck hangers occur at all main and sub-panel points and are spaced 76 feet apart centre to centre transversely, that is, as for the main trusses. There are forty bays of flooring, comprising twelve of 42 feet 9 inches each and twenty-eight of 35 feet 3 inches each, the longer bays being adjacent to the main piers, six at each end of the main span.

The deck system consists of cross girders at each pair of hangers, with longitudinal floor beams spanning between the cross girders, transverse floor joists spanning across the longitudinal floor beams, and longitudinal pressed steel troughing carrying the road concrete on top.

The roadway troughing is filled to the crests with concrete and a 3-inch thick reinforced-concrete slab is placed on top. The slab is topped with a 2-inch thick concrete wearing surface, and is securely anchored to the troughing by hoops 8 inches apart centre to centre, welded in-situ to the troughing and to the slab reinforcement. The footways are carried on cantilever brackets built on the ends of the cross girders, and the paving consists of a 3-inch thick reinforced-concrete slab with a $1^1/_2$-inch thick surface paving of Indian Patent Stone.

Fabrication of Steelwork

The fabrication of the steelwork in the monolith curbs and in the superstructure generally was carried out in Calcutta by the Braithwaite, Burn and Jessop Construction Company Ltd. as sub-contractors to the Cleveland Bridge and Engineering Co. Ltd. The steel for about 23,500 tons out of a total weight of 26,500 tons of permanent steelwork, was supplied by the Tata Iron and Steel Company Ltd., Jamshedpur. The remaining 3,000 tons, including wide plates and a number of special items were made in England.

The creeper cranes, all major items of plant and a further 2,500 tons of steelwork for temporary structures were also made in England.

In the fabrication of the members, web plates were batch-drilled to templet, the holes for end connections being left $^1/_8$ inch small. All templets were of steel with case-hardened steel bushes and were sent to each shop as required. Chord members were boxed on rectangular cast-steel diaphragms, machined all over and connected by turned bolts to pilot holes drilled in the member.

For the finishing of all main connections the members were assembled and levelled at Victoria Works, with gussets and covers in position and with butt joints drawn up tight. The angles of intersection were then checked by theodolite after which the rivet-holes were drilled out full size and the covers were marked for position.

The fabrication was very good and suffered in no way from being carried out in four separate shops; for example, a careful check on the full length of the lower chord of the anchor arm, comprising eight members, showed that it was correct to within 5/64 inch on an overall length of 325 feet.

Erection of Superstructure

Creeper Cranes

The general scheme of steelwork erection was based on the use of two creeper crane units designed by the main Contractors in collaboration with Messrs. Wellman, Smith, Owen. Each unit consisted of two 60-ton derricking cranes, capable of unlimited slewing in either direction, mounted on a wheeled undercarriage and having a total weight of 610 tons. In addition to the main hoist, capable of lifting 60 tons at 40-feet radius, the jibs carried a 20-ton auxiliary hoist with a maximum radius of 90 feet. To compensate for the varying gradients on which they had to work, the whole of the upper part of the cranes was pivoted on the undercarriage; the axes were kept vertical by means of screw levelling gear between the back of the crane and the carriage.

The cranes had to be capable of hauling themselves up the top chord of the anchor arms (a slope of more than 30 degrees), crossing the tops of the towers, lowering themselves down the slope of the cantilever arms, and moving along the horizontal chords of the suspended span. They moved on double-flanged wheels on pairs of rails riveted on to fleeting tracks, which consisted of heavy box girders bolted on to stools fixed at intervals of 12 feet or so on the upper chords. The fleeting tracks were dismantled behind the crane and re-erected in front of it, special lengths being used at the changes in angle between panels.

Erection of Anchor Arms

The Anchor Arms were erected on falsework, for which extensive temporary foundations were required owing to the heavy loading which had to be taken on bad ground.

The temporary foundations on the Calcutta side consisted of groups of "Vibro" piles with reinforced concrete caps, whilst on the Howrah side displacement rafts were used except where the supporting trestles had to be located over an old graving dock. These trestles were carried on heavy reinforced-concrete pillars which were in turn supported by heavy reinforced-concrete beams to spread the load across the whole width of the deck and on to the massive brick walls on either side.

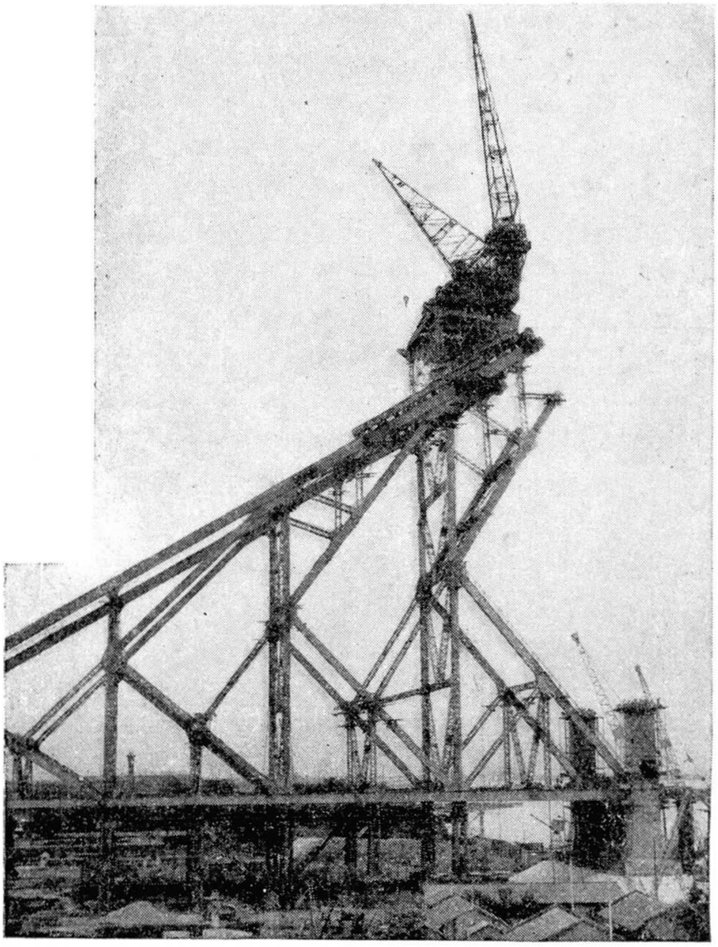

Fig. 4. Erection of Howrah Anchor Arm nearly completed.
Note temporary members in truss.

The erection commenced at the main piers and the lower part of the anchor arm was erected as the crane was moved back panel by panel towards the anchorage where the crane moved on to its special cradle previously erected on a temporary steel ramp behind the Anchorage. The crane then erected the upper part of the anchor arm as it was moved forward complete on its cradle, up the slope of the anchor arm. Fig. 4 shows the erection of the Howrah Anchor arm nearing completion.

The creeper crane, in the position shown in Fig. 4, completed the erection of the tower with saddles surmounting the two posts. The erection of the anchor arm was completed by making the connections between the saddles and the members which are attached thereto.

As the design of the superstructure is based on the principle of pre-stressing the members during erection, it was necessary to strain the top of the tower back about 13 inches in order to complete the above-mentioned connections. This operation was carried out by means of hydraulic jacks; a force of about 140 tons in the jacks being required at each tower.

Erection of Cantilever Arm

After completing the above-mentioned connections, the crane was moved forward close to the saddles. The lengths of cantilever arm members attached to the saddles were then erected together with the requisite temporary members to provide a stable framework to receive the creeper crane. The crane was then moved forward, on its own undercarriage, over the top of the tower and on to the cantilever arm. The cradle was then dismantled. In the early stages of the erection of the cantilever arm a considerable amount of pre-stressing was needed to complete the connections. As erection proceeded, however, the stresses in the members of the anchor arm approached more and more closely to the final condition; the weight of the cantilever gradually strained the top of the tower forward towards its final position and the amount of pre-stressing required at each panel in the cantilever arm was accordingly reduced.

Erection of Suspended Span

The suspended span was designed so that in the final condition it hangs on four vertical links which are pin-connected to the ends of the lower chords. It is restrained laterally by universal joints with sliding bearings located at the centre of the end lower transverse members of the suspended span and cantilever arms. Longitudinal restraint is provided by locating gear which is situated each side of the above-mentioned universal joints. This locating gear does not interfere with the expansion and contraction of the structure but is designed to centralise the suspended span between the two cantilever arms.

The two halves of the suspended span were erected as cantilevers. Groups of hydraulic jacks and screw jacks, acting horizontally, were provided at the four lower chord junctions with the cantilever arms, by means of which the two half-spans could be jacked towards each other. Similar groups of hydraulic jacks and screw jacks were provided at the upper chord junctions, but as these connections were in tension, telescopic temporary members were provided so that forward movement of the two half-spans could be effected by releasing the pressure in the jacks. Each groups consisted of two 800 ton hydraulic jacks and four "screw-jacks" or adjustable stops, which were designed for sustaining purposes only up to a load of 450 tons each.

Closure of suspended span

The normal intention was to close the gap more or less equally from the two sides, but the range of movement provided in the jacks was such as to enable the complete closing operation to be carried out from either end of the suspended span in the event of a failure, during the final operations, of the jacks at one end. The range of movement also made full provision for temperature effects and stress deformation of the superstructure, and for initial variations in the actual centre-distance of the main towers. Special temporary connections with tapered pilot pins were provided at the centre of the suspended span to facilitate alignment of the abutting ends of members during the closing operations.

The final operation was divided into three parts, namely, closing the lower chord, closing the upper chord, and swinging the span. All three operations were carefully rehearsed beforehand, so that the staffs at the various points knew their duties at each stage. This was very important, as it was essential to complete the closure quickly before the chords were distorted by the full heat of the sun.

The closure began at daylight on 30th December 1941. The lower chord gap was closed first by jacking out the Calcutta half-span, using the eight 800-ton jacks at that end only. Fortunately clouds prevented the sun from affecting the steelwork appreciably until after 9 a. m. The residual gap of $^1/_2$ inch in the upper chord was then closed by releasing the pressure in the eight top chord jacks equally and simultaneously from both ends. By then the sun was having considerable effect on the steelwork, and the joints had to be squeezed together with a load of 200 tons each in order to get all the bolts fitted. The diagonals were then adjusted and their connections were completed. By that time it was midday, and the swinging of the span was begun. The final closure was effected by progressively reducing the pressure on all sixteen jacks simultaneously and by 1 o'clock the whole operation was completed and the span was suspended freely from the links at the four corners.

Erection of deck

The hangers, cross girders, and stringers were lifted by means of hand winches on the deck or bottom laterals working through tackles suspended from the superstructure overhead. This method proved quick and simple; a routine was soon established by means of which two panels were erected per week, and within three months after closure all the deck steelwork had been assembled and the riveting was well advanced.

The cross girders were assembled in pairs and riveted on one of the pontoons moored close to the shore on the Howrah side. The pontoon was taken out by two tugs and held immediately below each pair of hangers in turn. Each girder, weighing 22 tons, was hoisted by two hand winches working through 5-to-1 tackles hung from the lower lateral cross member immediately over it. By this means two cross girders could be erected and their pin connections to the hanger completed in a morning.

The floor beams, troughing, and kerbs were run out on decauville tracks laid on the rail bearers of the deck and skidded into position. The spot welding of the stirrups to the troughs, involving more than one million welds, was completed on special jigs at site before the troughs were erected. After the riveting was finished the reinforcement was placed and the roadway concrete was poured.

Approaches

Gradients

One primary factor affecting the layout of the approaches was the maximum permissible gradient for bullock and coolie carts, which still form a very large percentage of the goods traffic over the bridge. Experience over many years has shown that up gradients for this class of traffic must not be steeper than 1 in 40, whilst 1 in 36 is considered the maximum safe down gradient. These vehicles are very largely made in Indian villages and are not fitted with brakes.

Carriageway

The layouts were arranged, as far as possible, as dual roads, each carrying one-way traffic, with accommodation for four lanes of vehicles, namely, slow-moving bullock and coolie carts near the kerbs, a lane for horse-drawn vehicles, which still form a very large percentage of Calcutta's traffic, and two lanes for heavy and light motor-vehicles and trams. A liberal allowance of 10 feet per lane was fixed, making a total width of 40 feet for one-way roads. The footpaths are each 15 feet wide, as on the bridge.

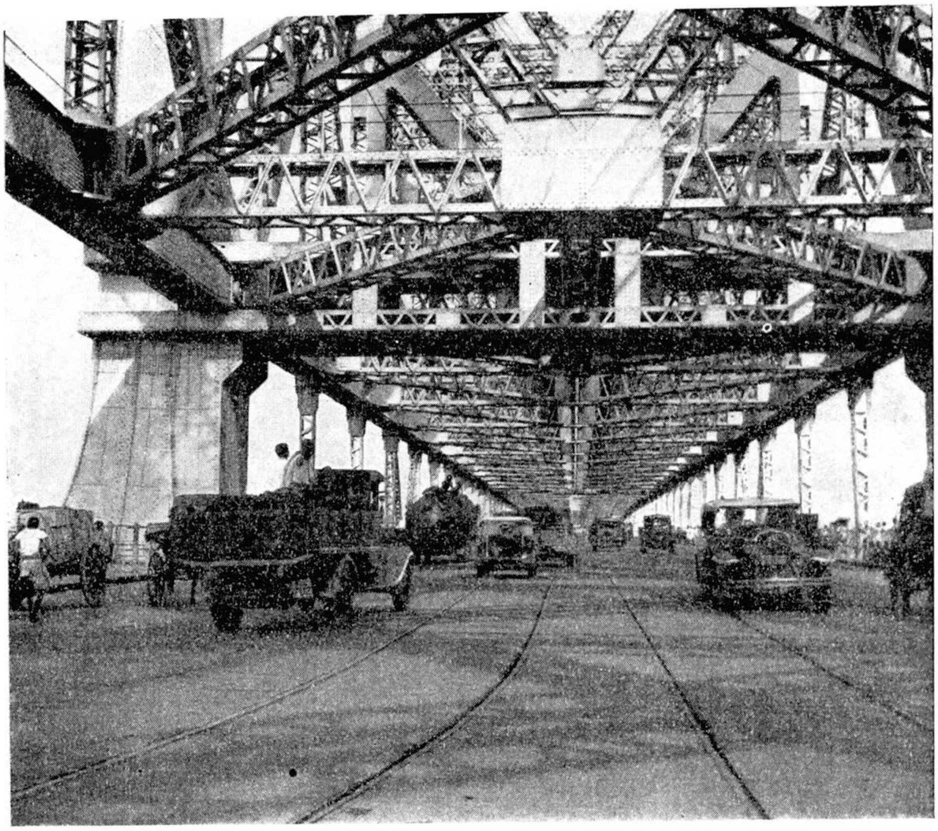

Fig. 5. Suspended deck viewed through main tower.

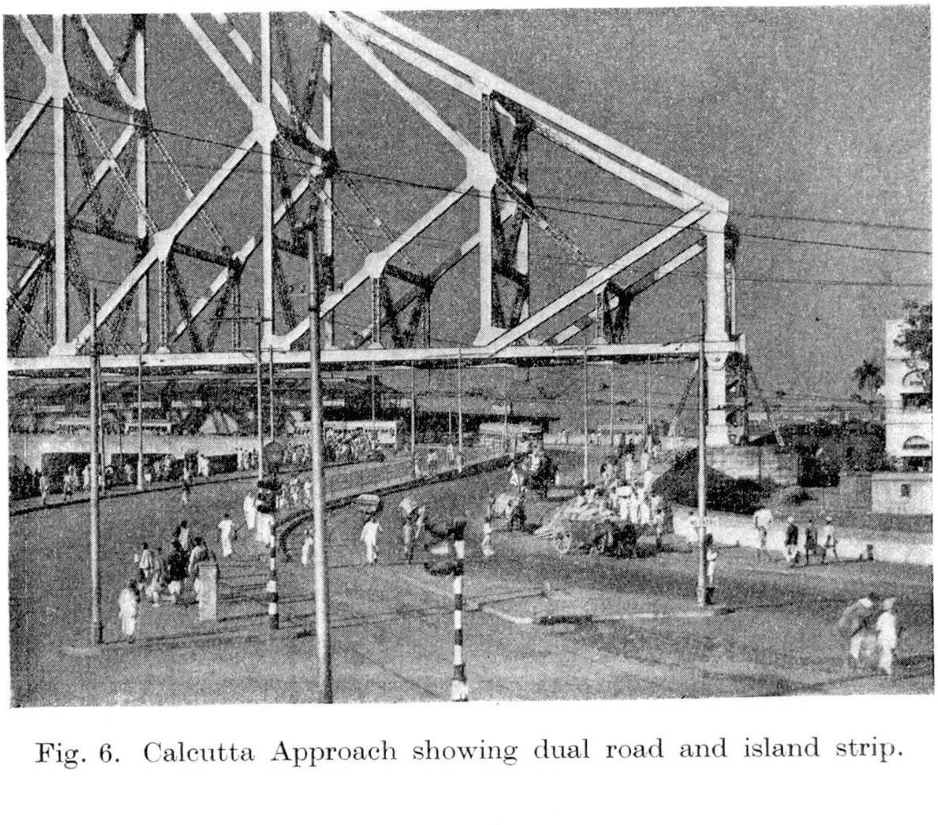

Fig. 6. Calcutta Approach showing dual road and island strip.

Lay-out

On the Calcutta side trams approach the bridge from three directions, and it was considered that the junctions of the tracks could best be arranged on a large island. The approach road from this island to the bridge is divided for "up" and "down" traffic by means of a long island strip, which also solved the problem of providing correct super-elevation coupled with easy gradient and enabled differences of adjacent levels of as much as 2 feet to be accommodated. This expedient also made it possible to improve the down gradient to 1 in $38^1/_2$ whilst provision is also made for the future northern approach; Fig. 6 is a view of the Calcutta Approach.

On the Howrah side, terminal arrangements are made for two separate tram services which necessitate the arrangement of complete turning circles, each with its own passenger shelter and an elevated tram-controller's signal-box. The bus terminus is also divided into two groups, namely, those operating in Calcutta, and those which operate in Howrah. Provision is also made for a western approach which will connect with the Improvement Trust schemes of development.

The arrangement of surfaces had also to provide for the requisite camber and, as far as circumstances would permit, for correct superelevation at all curves. All these considerations had to be borne in mind when planning the approach carriageway, whilst grading and cross-falls, as well as the construction, had to be arranged in such a way as to facilitate, without alteration to surface levels, the subsequent addition of the Calcutta Northern and Howrah Western approaches.

Type of Construction

The lower portions of the two approaches, that is, up to a height of 6 or 7 feet, are constructed on consolidated fill; but it was decided to adopt some form of comparatively light-weight hollow construction for the higher portions of the approaches, the maximum height of which is about 20 feet. The problem of the weight ruled out all heavy forms of construction, such as brick arches, whilst the areas involved were too extensive for any form of raft foundation. Accordingly, after trials on small areas, it was decided to remove the upper 4 feet or 5 feet of the soil and, after consolidating the ground by rolling, to place on it 18 inches thickness of mattress consisting of old broken brick, which was locally available, consolidated in layers by power-driven rollers and topped with 3 inches of mass concrete. On this were placed continuous strip footings of reinforced concrete, averaging about 6 feet in width and spaced at about 18 – 20 feet apart centre to centre, which carried a light-weight reinforced-concrete construction consisting of monolithic slabs and walls hinge-connected to the strip footings. This type of construction was readily adaptable to being built in separate units, in which no dimension in plan exceeded 100 feet, with permanent unfilled joints between units. Roadways are provided through the approaches, at ground-level, adjacent to each of the two main pier monoliths. On the Calcutta side a two-span frame bridge is provided for this purpose, and the passage of the Port Commissioners Railway is provided for by a single-span frame bridge. The approaches are contained within exterior walls having horizontal-coursed brick facing of machine-made bricks, thus giving the impression of solidly-filled construction. The parapets are in cut stone of 14-inch thickness and 3 feet 9 inches in height.

Under sections of the Calcutta approach near the bridge monoliths, the strip footings are carried on groups of Vibro piles driven to an average depth of about 40 feet.

Traffic over the Bridge

In May 1946 a comprehensive traffic census was carried out under the guidance of Professor Madhava, of the Government of India Roads Organisation and the summarised results are given in the Table I, which also gives figures obtained from a census of traffic over the Old Bridge in 1931. Comparable figures for London Bridge are also included in the table and provide an interesting comparison.

Table I.
Comparative details of Traffic over:
a) The Old Howrah Bridge; b) The New Howrah Bridge; c) London Bridge

	Type of Traffic (In both directions)	Old Bridge (Dec. 1931)	New Bridge (May 1946)		London Bridge (Aug. 1926)	
		Max. Hourly Totals	Max. Hourly Totals	Max. Daily Totals (24 hours)	Max. Hourly Totals	Max. 12 hour Totals (8a.mto8p.m)
	Pedestrians	not counted	16 900	121 100	not counted	
	Cattle	not counted	1 740	2 997	not counted	
Slow vehicles	Bullock Carts	233	190	1 951	NIL	NIL
	Horse Vehicles	119	153	1 577	256	2 462
	Hand Carts	278	490	4 289	97	596
	Rickshaws	not counted	400	4 265	NIL	NIL
Fast Vehicles	Motor and Pedal Cycles	171	453	3 246	458	2 884
	Motor Cars and Taxis	350	481	5 150	548	4 861
	Motor Lories	245	467	4 286	471	4 168
	Motor Buses	138	151	1 931	520	5 312
	Trams	NIL	85	1 227	NIL	NIL

High tensile steel

The physical properties of the high tensile steel used for the plates and sections, and for the rivets, are given in Table II.

Table II.

	Yield Stress: tons per sq. inch	Ultimate Tensile: tons per sq. inch	Elongation per cent	
			Longitudinal	Crosswise
Plates and Sections				
Specified	23,0 (min.)	37 to 43	18,0 (min.)	16,0 (min.)
Representative Samples				
Plain Manganese	24,5	37,6	25,0	—
(Home Steel)	24,6	40,8	19,0	—
Manganese Chromium				
Home Steel	24,3	37,2	23,0	—
	24,6	41,0	19,0	—
Indian Steel	23,7	37,3	25,0	—
	25,6	39,8	22,0	—
Rivet Bars			On 8 dias.	On 4 dias:
Specified	—	30 to 35	22,0 (min.)	27,0 (min.)
Representative sample bars (1)	—	31,9	27,8	—
Representative sample bars (2)	—	30,0	30,0	—
Driven Rivets	Specified driven shear value 26,0 t. p. sq. in. (min.)			
Rivets from above bars (1)	Driven shear values 26,77 to 27,7 tons per sq. inch.			
Rivets from above bars (2)	Driven shear values 25,47 to 27,7 tons per sq. inch.			

Estimate and costs

The estimated cost of the whole project as finally approved by the Commissioners, and the total cost of the work carried out, are as follows:

Item	Estimated Cost	Actual Cost
Bridge		
Foundations	468 963	440 978
Superstructure	1 139 858	1 145 319
Engineering Costs	143 100	163 364
Totals	1 751 921	1 749 661
Approaches etc.		
Approaches	235 578	199 630
Purchase of Land	247 260	330 370
Prelim. works, borings, drainage, experimental roads, etc.	50 444	50 217
Rent of Land and premises during construction	66 514	80 343
Transport of surplus earth	9 916	10 221
Road surfaces on bridge, inspection gantries, etc.	26 179	10 988
Engineering Costs	19 350	18 187
Contingencies	11 460	14 270
Grand Totals	2 418 622	2 463 887

Acknowledgments

The New Howrah Bridge and Approaches were designed, for the Commissioners for the New Howrah Bridge, by Messrs. Rendel, Palmer and Tritton, Consulting Engineers, Westminster, who were also Engineers for the Works.

The Cleveland Bridge and Engineering Co. Ltd. of Darlington were the main Contractors for the whole work, the fabrication of the steelwork being sub-let by them to the Braithwaite Burn and Jessop Construction Company Ltd. of Calcutta. The creeper cranes were designed by the main contractor in collaboration with Messrs. Wellman, Smith, Owen and Company Ltd.

The authors were respectively, Chief Engineer to the New Howrah Bridge Commissioners, and Chief Steel Bridge Engineer to Messrs. Rendel, Palmer and Tritton, and wish to express their thanks to the Commissioners and to the Consulting Engineers for permission to submit this paper. They are also indebted, for details of the execution of the work, to George Eric Howorth Esq., O.B.E., M.C., B.Sc., M.I.C.E., and Hubert Shirley Smith Esq., O.B.E., B.Sc. (Eng)., M.I.C.E., who were respectively Contractor's Agent, and Engineer in charge of the Calcutta side foundation work and of steelwork at site.

Summary

This paper describes the design and construction of the new cantilever highway bridge across the River Hooghly between Calcutta and Howrah. The new bridge, which was opened to traffic in February 1943 replaces the old floating bridge which was built in 1874. It has a span of 1,500 feet and provides accommodation for eight lines of vehicles and two footways for pedestrians. The bridge deck, which covers the river span only, is suspended below the main trusses. The approach roads below the anchor arms are of reinforced concrete construction and are independent of the superstructure.

The erection of the superstructure was carried out by means of two creeper cranes, the two halves of the suspended span being built as temporary extensions of the cantilever arms.

The two main piers each consist of large reinforced concrete monoliths which were sunk by open-dredging, some of the dredging shafts being plugged in the open and the others under compressed air. Small monoliths of similar construction were used for the anchorages.

The superstructure contains approximately 25,000 tons of steel, approximately 70% of which is of high tensile structural steel.

A traffic census in 1946 produced the interesting figures of 121,000 pedestrians and 28,000 vehicles per twenty-four hours.

Zusammenfassung

Dieser Beitrag beschreibt den Entwurf und den Bau der neuen Auslegerbrücke über den Hooghlyfluß im Zuge der Straße Calcutta-Howrah. Die neue Brücke, welche für den Verkehr im Februar 1943 freigegeben wurde, ersetzt die alte Pontonbrücke vom Jahre 1874. Sie besitzt eine Spannweite von 1500 Fuß und ermöglicht die Überführung von 8 Fahrzeug- und 2 Fußgängerstreifen. Die Fahrbahntafel der Brücke über dem Flußfeld ist an die Hauptträger aufgehängt. Die Zufahrtsrampen unter den Widerlagerarmen sind aus Eisenbeton und unabhängig vom Überbau.

Die Montage der Träger geschah mit Hilfe von zwei Creeper-Kranen, wobei die zwei Hälften des Mittelfeldes als temporäre Auskragungen der Auslegerarme vorgebaut wurden. Die zwei Hauptpfeiler sind große, armierte Betonblöcke, welche abgesenkt wurden durch offenes Baggern, wobei einige der Senkkasten in offener Baugrube abgeteuft wurden, andere hingegen unter Druckluft. Kleinere Blöcke ähnlicher Art dienten als Widerlager.

Der Überbau benötigte ungefähr 25 000 Tonnen Stahl, wovon ungefähr 70% hochwertig waren.

Eine Verkehrszählung im Jahre 1946 ergab die interessanten Zahlen von 121 000 Fußgängern und 28 000 Fahrzeugen in 24 Stunden.

Résumé

Les auteurs décrivent le projet et la construction du nouveau pont cantilever par lequel la route de Calcutta à Howrah traverse la rivière Hooghly. Ce pont a été ouvert au trafic en février 1943; il remplace l'ancien pont de bateaux qui datait de 1874. La portée est de 450 m. Le tablier est suspendu aux poutres principales au-dessus de la rivière; il permet le passage de front de huit véhicules; le pont comporte également deux passerelles pour piétons. Les rampes d'accès, en béton armé, sont indépendantes de la superstructure.

Le montage des poutres a été réalisé à l'aide de deux grues à cheminement, les deux moitiés de la travée centrale étant construites sous forme d'encorbellements temporaires par rapport aux parties en cantilever. Les deux piles principales sont constituées par de gros blocs de béton armé foncés par excavation à ciel ouvert; quelques-uns des caissons ont été foncés en fouille ouverte et d'autres à l'air comprimé. Des blocs semblables mais plus petits ont été utilisés pour la construction des appuis.

La superstructure a nécessité environ 25 000 tonnes d'acier, dont 70% environ d'acier à hautes caractéristiques.

Un contrôle de circulation effectué en 1946 a donné les chiffres intéressants de 121 000 piétons et 28 000 véhicules en 24 heures.