PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

River Thames - Removable Flood Barriers

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River Thames – removable flood barriers

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Following upon the severe flooding from an exceptional tide cum surge in February 1953 a removable flood barrier in Long Reach was considered as the basis of a flood defence system compatible with the navigation interests yet avoiding the high cost of bank raising in the metropolis.

Three designs of barrier were developed and costed, each embodying two 150 m wide navigation openings. The preferred system incorporated drop gates supported on high towers above shipping when not in use.

The navigation authorities ruled that an unobstructed opening at 425 m was necessary and a new design exercise found in favour of retractable barrier structures but at increased cost with less reliability in performance.

The formation of the Greater London Council led to a wider investigation of possible barrier sites and the lesser use by shipping of reaches above the Royal Docks permitted narrower openings. Schemes for some six different sites and over 40 variations in span arrangement were investigated and led to a proposal for four 60 m navigation openings in Woolwich Reach which might be closed by a form of rising section gate. This has proved to be the cheapest, most reliable and quickest to install of all the schemes investigated and is now the basis of design for contract.

In February 1953 a spring tide high water nearly coincided with a large surge produced by atmospheric depression. Widespread flooding took place in the River Thames estuary inundating 120 km^2, drowning 300 people and causing extensive damage. To prevent a recurrence of such a disaster, it was apparent that the river banks needed to be raised by an amount that varied from one location to another, having regard to the increasing tidal range that one meets when proceeding upstream and the freeboard to meet wave action in exposed areas.

A committee was formed under Lord Waverley to advise on the bank heightening and recommended that this be generally 1.8 m above the maximum recorded in 1953. Work on bank raising was immediately put in hand to protect the areas actually flooded, but due to difficulties in the metropolitan area, an alternative to bank raising was considered in the form of a removable barrier to be sited in Long Reach. The suggestion arose from Mr A. Price, who was conducting model experiments for the Hydraulic Research Station in which the tide-cum-surge and flooding of February 1953 was simulated.

Two firms of consulting engineers specializing in maritime works were appointed by the Ministry of Housing and Local Government to investigate the feasibility of such a removable barrier. I am a partner in one of these firms, and interested myself in finding how a barrier would work if built full size.

In other papers presented to the Royal Society the warning system has been described as derived from two separate disciplines, namely, barometric synoptic charting, and water-level measurement at a number of coastal stations. The measurement of tidal levels permits of the accurate forecasting of a level of a tide-cum-surge at London Bridge but gives only 4 h warning before the event. This is due to the comparative shortness of our coastline and the speed of the tidal wave.

The longer warning period possible from the study of synoptic charts is, unfortunately, subject to serious error because we still cannot forecast our weather with the necessary precision. Given only 4 h warning – at least 1 h of which would be needed to stop shipping – how can a removable structure arrest the movement of the river weighing many millions of tons and flowing inland at its maximum speed under the pressure of an exceptional tide-cum-surge?

Under such conditions the introduction of a barrier causes a raising of level of the river surface downstream and a depression of the surface upstream. These disturbances move away from the barrier at a speed which is a function of the water depth, and with vertical dimensions which are functions of the river velocity and depth. The frontal shape of the disturbances, which have been called reflected waves, depends on the manner in which the barrier is closed. Rapid closure will produce a steep front. These disturbances arrest river movement by a conversion of kinetic energy into potential energy, but will be modified in height and form in their passage along the river by bends and changes in river cross-section.

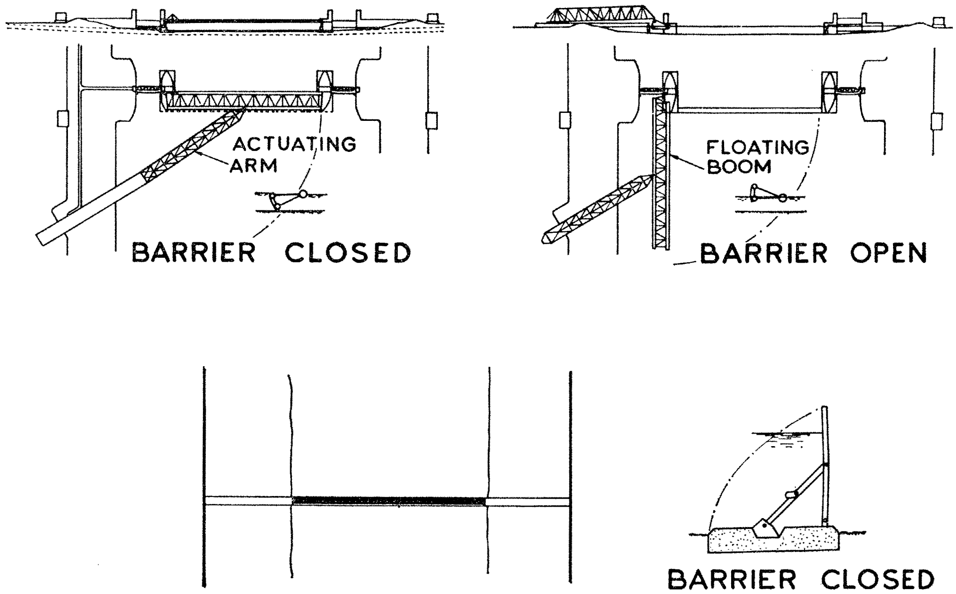

FIGURE 1. Floating swing type barrier (top) and rising shutter type barrier (bottom).

To leave the river clear for shipping yet be able to arrest its movement by introducing a major structure in the form of a barrier at short notice is a formidable engineering proposition. How could such a structure be designed to give reliability in service comparable with that of raising the river banks? It so happened there were plenty of suggestions for the public imagination had been stimulated, and the Ministry of Housing and Local Government were inundated with proposals. The Ministry passed all these proposals over to the consulting engineers. Figure 1 shows some of these proposals which are typical. The top diagrams show a floating barrier designed to be swung into position like a door and controlled by a strut operated from a mechanism housed on one of the river banks. The strut loading which is of the order of 300 MN (30000 tons-force) is too high to be manageable. The lower diagram indicates the type of barrier which would rise up from the river bed. There were a number of suggestions, along these lines but of course they involve mechanisms which would be inaccessible and difficult to maintain.

Figure 2 shows on the top left a proposal for a barrier formed of floating caissons which could be drawn into position like a necklace. Manoeuvrability would be difficult if not impossible in a fast-moving waterway such as would obtain at time of closure. The top right shows a type of barrier inspired by the traditional ship caisson but again unsuitable since such caissons can be installed only at slack water. The proposer of the bottom left-hand system had in mind meeting the difficulties of maneouvre in a strong current by use of an open lattice structure which would presumably be infilled when once in position. This is a practical suggestion and basis of many of the sechemes we have developed. The bottom right-hand diagram illustrates an ingenious system for stopping the river. A number of gates normally housed flat on the river bed would be centre pivot mounted and held in position by piers in the river. The mounting would allow the gates to be raised while still presenting an end-on attitude to the river flow. Once raised to a suitable position the gates would be turned about the axle to take up a vertical attitude, something in the manner of a butterfly valve.

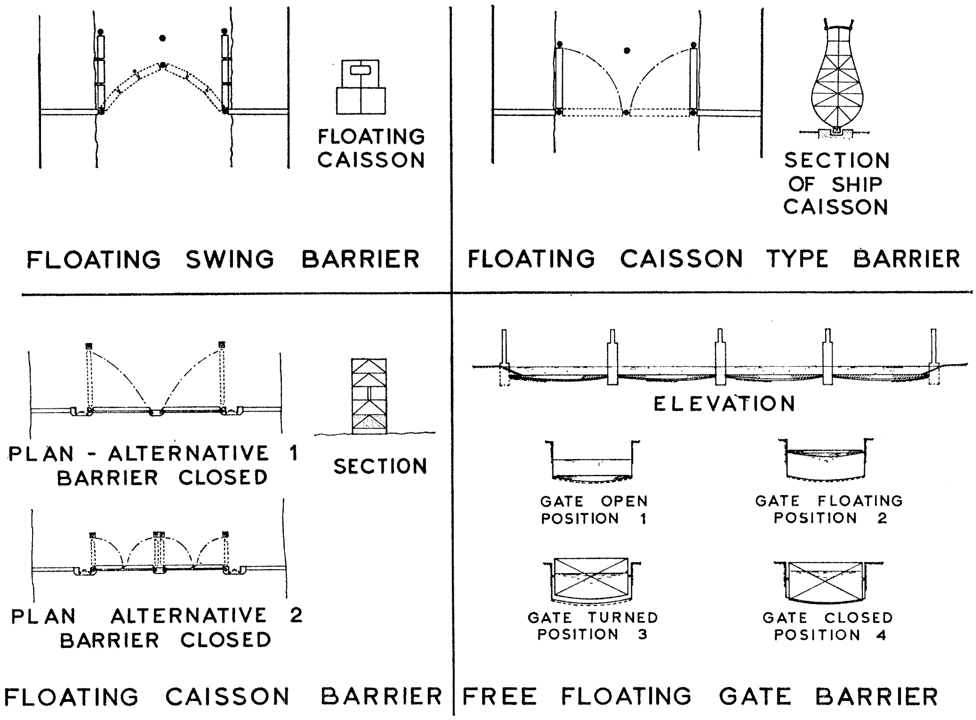

FIGURE 2. Floating type barriers.

Depending on its location, a barrier can reduce the need for bank raising over many kilometres, but since the Thames is busy with shipping, concern was expressed by the River Authorities lest the opportunities of river transport be impaired. It was thought essential that any barrier must be removable and capable of introduction only at times of genuine flood danger.

On such occasions the penalty for failure to close the barrier is unacceptable so that reliability of operating mechanism is of paramount importance. It would not be satisfactory following an abortive attempt to prevent the flooding of London to say, 'we did our best with the barrier, we managed to close a lot of it but weather conditions were dreadful, and we are sorry we did not succeed'.

There are in existence few structure meeting this requirement, and none on anything like the same scale. In our search for existing structures which might be suitably adapted, we studied the Dethridge retractable barriers across the Murray River, near Melbourne, Australia. These barriers are used to retain water in the dry season and thus permit the continual use of the waterway by shipping. Although not used for flood prevention, the feature of retractability has proved to be serviceable save in the event of heavy deposition of materials carried along by the river. Figure 3 shows the location of one of the two Dethridge weirs. A by-pass lock can be seen provided to permit the passage of vessels when the weir is established in position. The positioning of a dredger to remove river-borne material and permit the removal of the barrier, is shown.

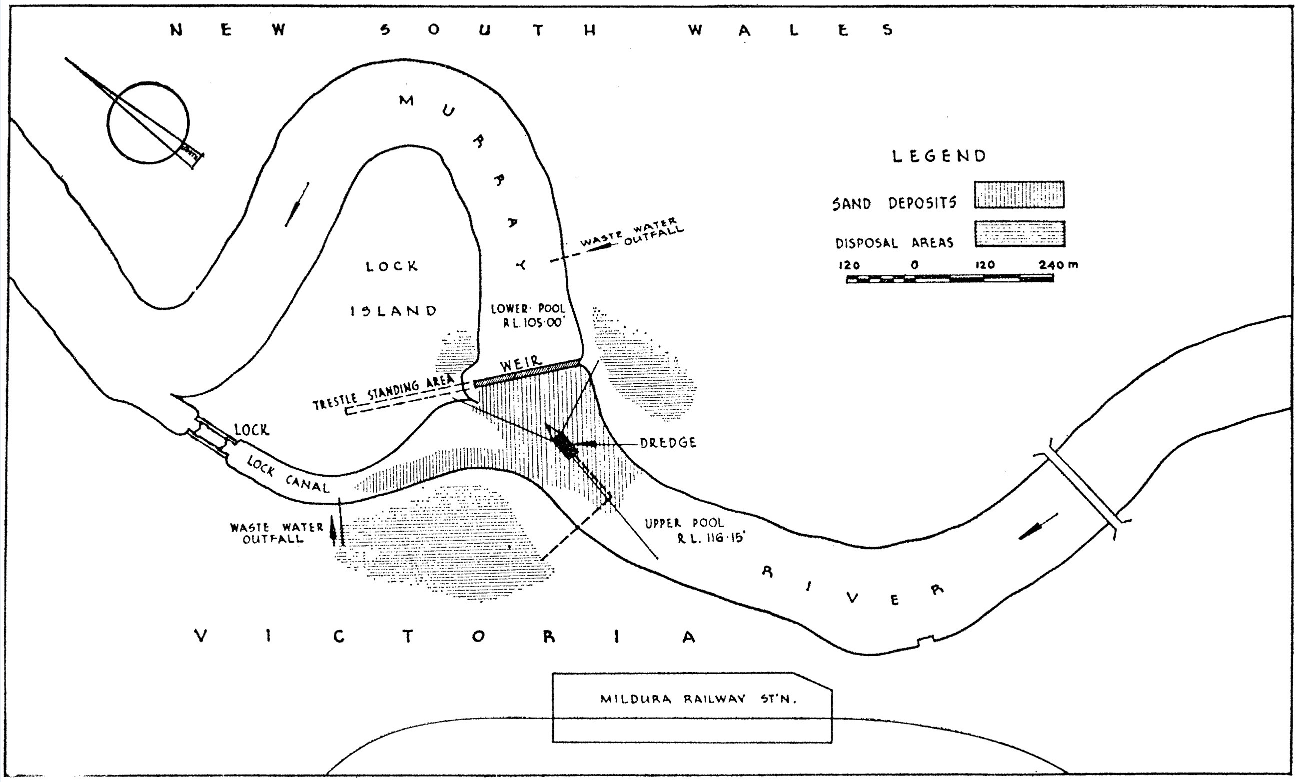

Figure 3. A retractable Dethridge weir.

Figure 4 shows at the top a cross-section through the weir which is constructed somewhat like an Irish bridge and carrying three railway lines. Two of the lines are disposed to resist vertical loading and one to resist horizontal forces. The barrier consists of a series of wheel-supported frames which can travel on these rails and so shaped that once in position they can be infilled with planking to obstruct river flow. The centre view shows the weir in position, and it can be seen that the frames are normally stored above water on the river bank. When moved into position the frames travel down an incline rather like a string of railway trucks. Figure 5 shows a close-up of the frames. The axles of the wheels taking lateral thrust can be seen in the foreground. Figure 6 shows the Dethridge weir or barrier in operation sustaining a water-level difference of some 3 m. A certain amount of leakage is evident. Figure 7 shows the trestles being moved as open frameworks.

More recently, to combat flooding by the type of tide-cum-surge experienced in the Thames a removable barrier in the form of a drop gate has been installed across the River Ijssel, near Rotterdam, as shown in figure 8. Provision is made for the drop gate to be duplicated. The barrier may be positioned well in advance of a danger period since a by-pass for shipping is provided in the form of a lock. The clear span is 80 m, and the barrier is designed to operate in a depth of

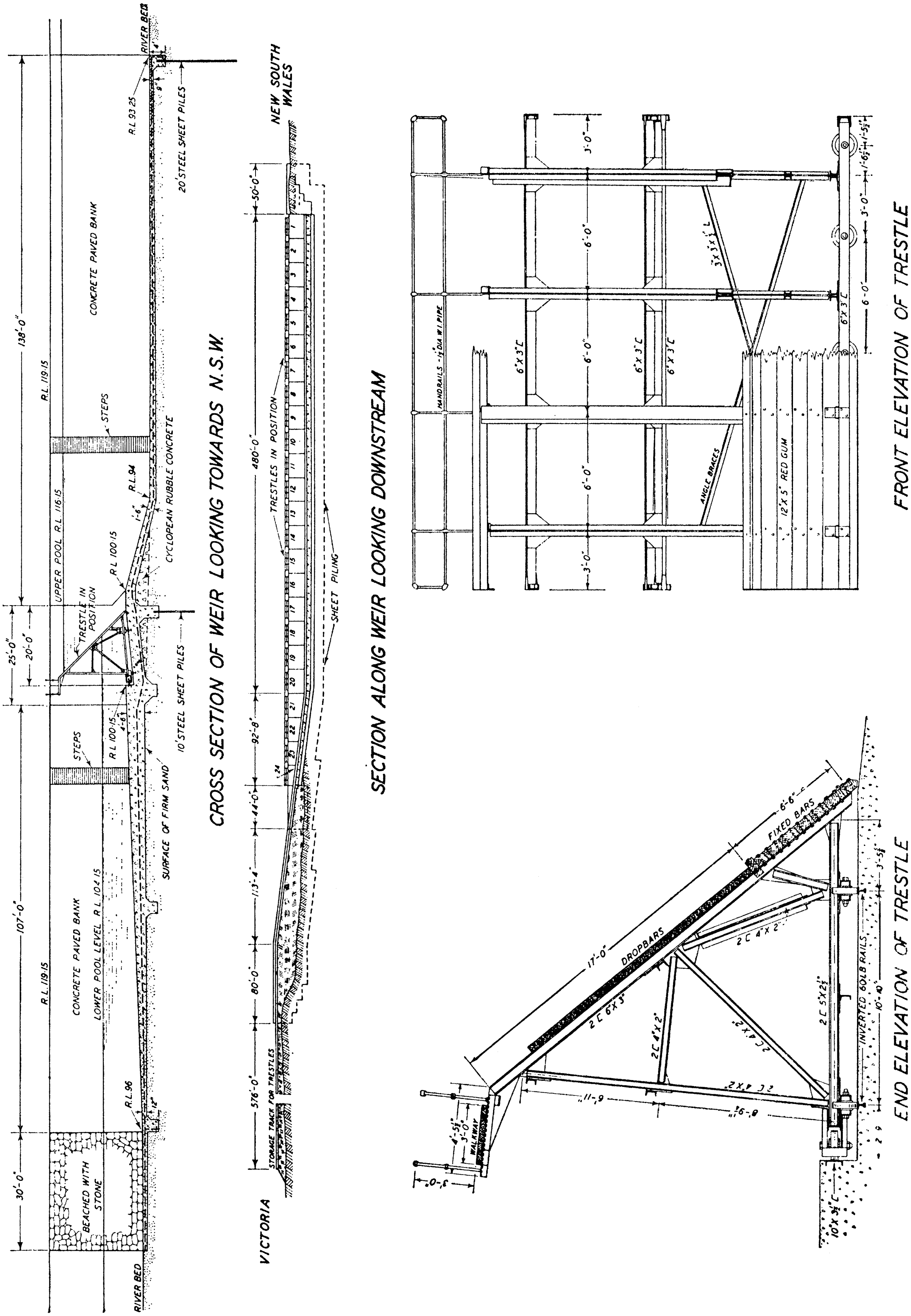

Figure 4. Lock and weir no. 11, Mildura – typical sections of the weir.

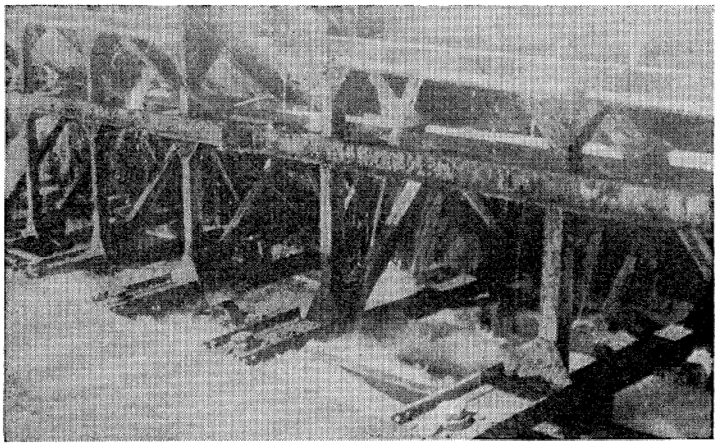

FIGURE 5. Close up of frames.

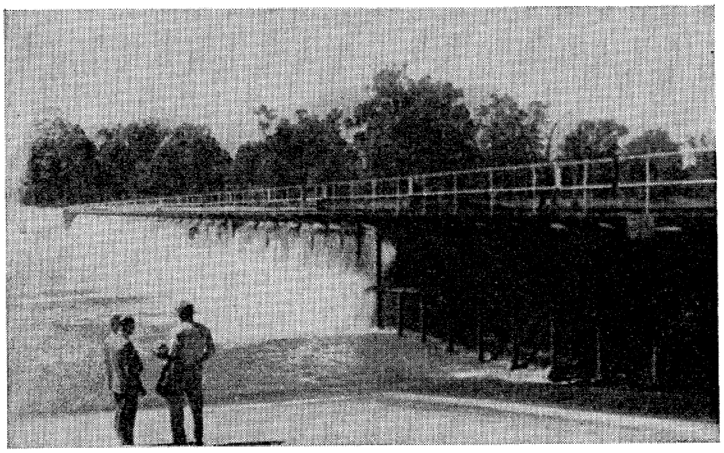

FIGURE 6. Dethridge weir in operation.

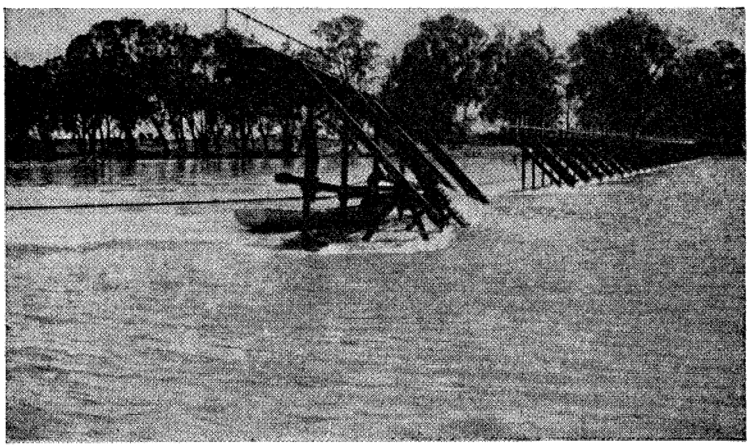

FIGURE 7. Mildura weir trestle unit moving into position in the river.

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water at high tide plus surge of 11.6 m. This may be compared with the depth at Long Reach of 23 m or 17 m in Woolwich Reach. There is much less river traffic than in the River Thames.

An important aid to the studies made by the consulting engineers was a decision on the width of navigation openings reached by the Thames Technical Panel after a series of consultations with the navigation interests. These openings for a barrier in Long Reach were fixed as two of 150 m to be flanked on each side by one of 75 m giving in all 450 m of navigable space but obstructed by three piers. A removable barrier was found to be feasible despite severe engineering problems. For instance, to permit of a late but emergency closure the structure must be

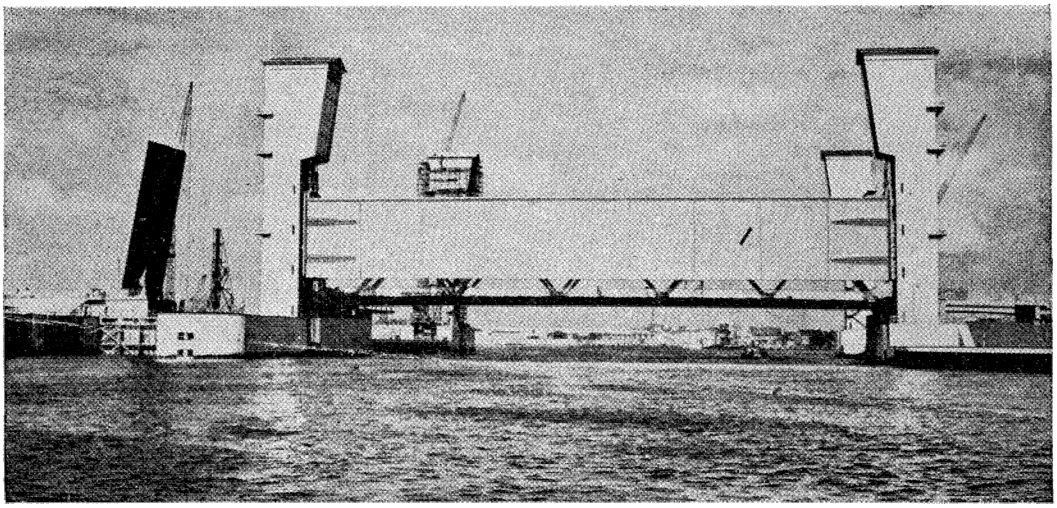

FIGURE 8. Storm weir and lock at Krimpen, Holland, across the river Ijssel.

capable of introduction into a fast flowing waterway. To combat the high velocity in the order of 3 m/s, it was considered necessary to introduce first a skeleton structure into the water thus minimizing the loading under which it needs to be moved. Following the positioning of the skeleton structure, smaller filling pieces can be positioned one at a time. This principle has proved effective on the Murray River barrier but needs to be carefully designed if it is not to be a slow operation. Of the various means of positioning the structural skeleton, three were found to be feasible. In one system the framework would be slid into position by horizontal movement, i.e. retractable. The normal disposition of the retractable framework would be clear of the river in dry dock. The girders could be supported by rollers as cantilevers and moved into position clear above the river bed so that wreckage or siltation would not impede movement.

In an alternative scheme the barrier structure could be positioned from cantilever arms moved in the manner of a swing bridge.

After considering all these alternatives, the favoured and most practical system, however, was one in which the framework would be lowered between two towers disposed so that in its open position a vessel could pass beneath the framework.

Figure 9 shows a form of retractable barrier which is somewhat different from that used across the Murray River. There are two rigid barrier structures normally housed in dry docks, one at each side of the river. The top view shows one of the structures emerging from the dry dock. It will be noticed that the structure is cantilevered so that its underside is substantially above the river bed ensuring that its movement would not be obstructed by sand or silt. Once in

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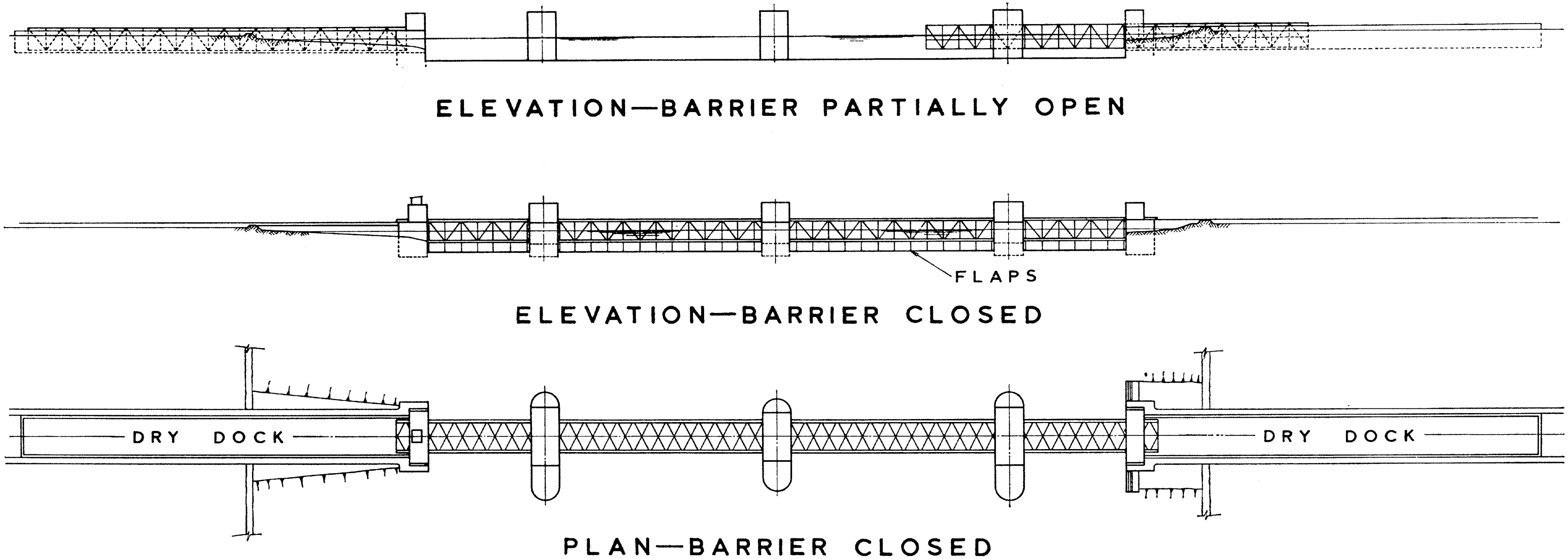

FIGURE 9. Retractable type barrier.

position, as shown by the centre section, flaps would be lowered from the underside of the lattice structure to seal the opening – the completion of the seal being made by sluices carried within the structure.

Figure 10 shows a swing barrier scheme in which supporting structures would be carried on piers and normally housed at right angles to the line of the barrier and parallel to the river banks. To obstruct the river flow the structure would be swung as shown in the lower diagram after which flap gates supported underneath the girders would be hinged down to take a bearing on to abutments suitably arranged at river bed level.

Figure 11 shows a lifting type of barrier consisting of girders which could be raised or lowered between towers in the manner of a lift bridge. The girders would carry flaps on the underside, and to close the river they would be lowered to register against the abutments on the river bed in a manner similar to the swing barrier.

At this stage a feasible barrier might have been constructed for a cost of approximately £15 M. However, re-consideration was given by the navigational authorities to the requirements for openings in the light of a trend in shipping towards the use of larger vessels, and it was decided that the clear navigable opening in Long Reach should not be less than 427 m. This led to a new feasibility study, out of which it became apparent that the only system that could be developed would be on the retractable basis. Two schemes were studied in sufficient detail to pronounce on feasibility, but the necessary standard of reliability could not be claimed.

Figure 12 shows a scheme for closing a 427 m opening with wedge-shaped barrier units positioned by means of two girders housed in dry docks and each capable of cantilevering 213 m against the force of river flow. Reaction forces would be taken on sturdy piers through hydraulically balanced rollers engaging with the bottom chord of the girders. To reduce the effect of dead weight, the bottom chord is designed as a streamlined tank giving partial support by buoyancy. To minimize the effect of river flow, the girders would be of lattice construction and arranged to carry the wedge shaped dam units above water level on their seaward side. When the girders are positioned across the river, the dam units would be lowered on to the river bed to engage with abutments at bed level when they would relieve the positioning girders from all lateral loading. A large-scale working model of this system was constructed as an aid to proving the feasibility of such a barrier.

On its formation, the Greater London Council was charged with the responsibility of flood protection of the London area and sought a solution in which an improved standard of reliability might be found by siting a barrier farther up the river and increasing the extent to which banks should be raised downstream. Due to the lesser use by shipping of the upper reaches, coupled with the planned closure of London Docks, Surrey Docks and Millwall Docks, it was found possible to adopt a narrower navigable opening. In all, some five different sites were considered and 40 different schemes investigated and costed. The schemes for the most part favoured drop gates for which the maximum span had been found to be about 150 m. However, for Long Reach a design was prepared for a drum gate system as alternative to the retractable barrier system for the 427 m opening. Drum gate barrier elements would be housed in recesses in the river bed. These recesses would normally be dewatered but on flooding would cause the barrier to close.

Horner (this volume, p. 184, figure 4) shows a drop gate scheme for Woolwich Reach. Such a barrier might be closed and used in the manner of a barrage during periods of emergency. To accommodate shipping there is a by-pass lock on the right-hand side. Such a barrier would of course be an impressive feature of the landscape.

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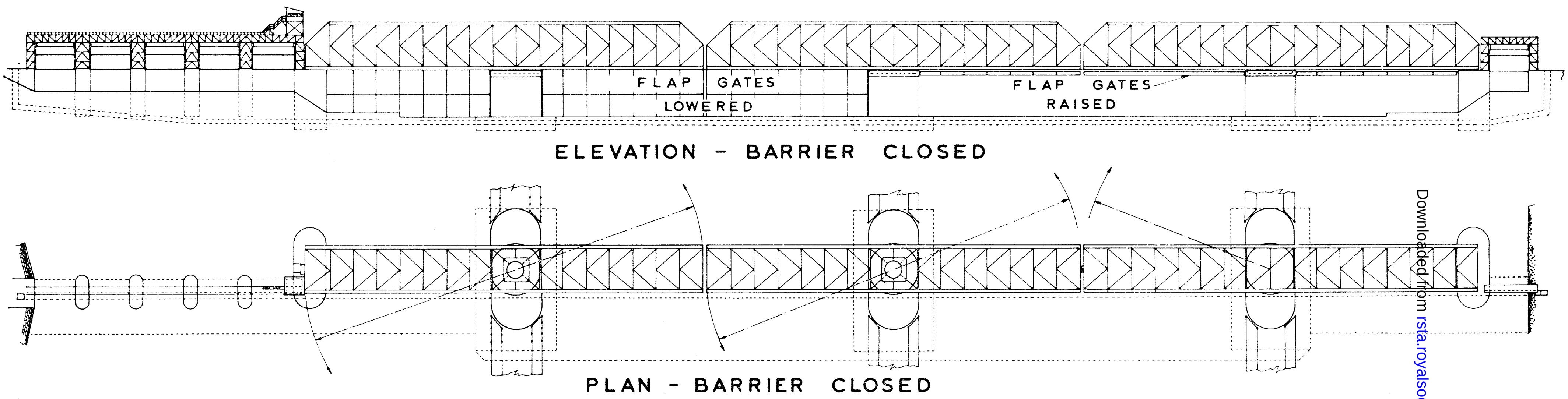

Figure 10. Swing type barrier.

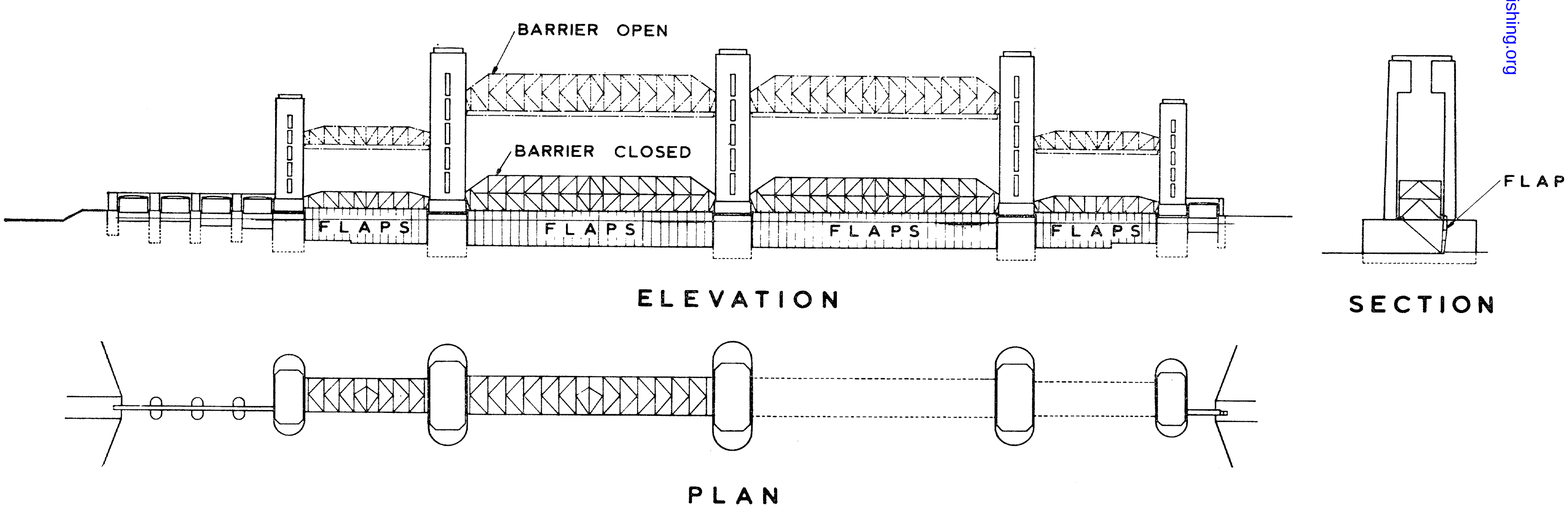

Figure 11. Lifting type barrier.

During the course of the investigation, the appearance of barriers of this type came under criticism due to the obtrusive nature of high towers necessary to support the gate in its open position clear above shipping. The greater freedom of study with regard to width of navigable openings led to the proposal that if these could be reduced to 60 m a simple and reliable form of rising sector gate would become possible. This was investigated in connexion with the site at Woolwich where excellent foundation conditions on chalk can be found. A sector gate can be moved into position across waterways having high velocities with relatively little effort since water pressures are resolved through the axle. To some extent the proposal was inspired by the horizontally mounted sector gates recently completed at Haringvliet in Holland as part of the delta scheme. The magnitude of the structure is comparable with a barrier at Woolwich, but the gates are used merely as sluices and do not permit of navigation.

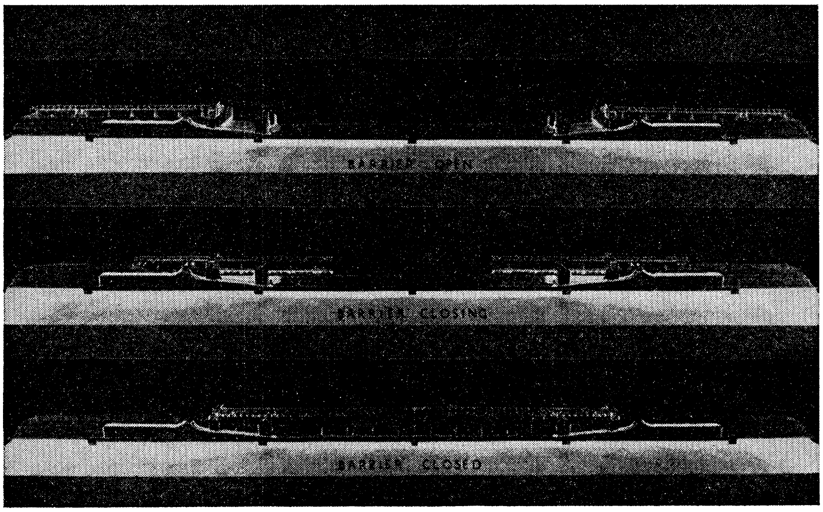

Figure 12. Operation of retractable barriers.

Figure 13 shows the Haringvliet sluices. The bottom view shows how the sill is constructed substantially above the river-bed level and the position of the two sector gates which find their support from triangular girders which carry a road crossing. The gates are operated by hydraulic rams through a system of linkage arranged to keep moving parts out of the water. The gates when open are in a raised position from which they may be lowered on to a sill in order to close the waterway.

Such a barrier is not suitable for the Thames which requires that the sill be well below the bottom of shipping. To provide sufficient clearance, the gates must be housed in the sill and raised by rotation about its supporting shafts when river flow is to be obstructed. There can of course be no projecting structures between the piers so that intermediate support for the sector, as featured in the design at Haringvliet, is not a possibility for the Woolwich barrier.

Figure 14 shows the general form of a segment gate which has been designed for the site in Woolwich Reach, and estimated to cost, with shore installations necessary for control and maintenance, £36.5 M. The top view shows the general river profile and the manner in which the sills have been arranged. The centre plan view shows how the piers are disposed in a staggered manner to allow the accommodation of operating machinery in minimum width. The lower right-hand view shows how the gate section is housed when the barrier is open and that on the

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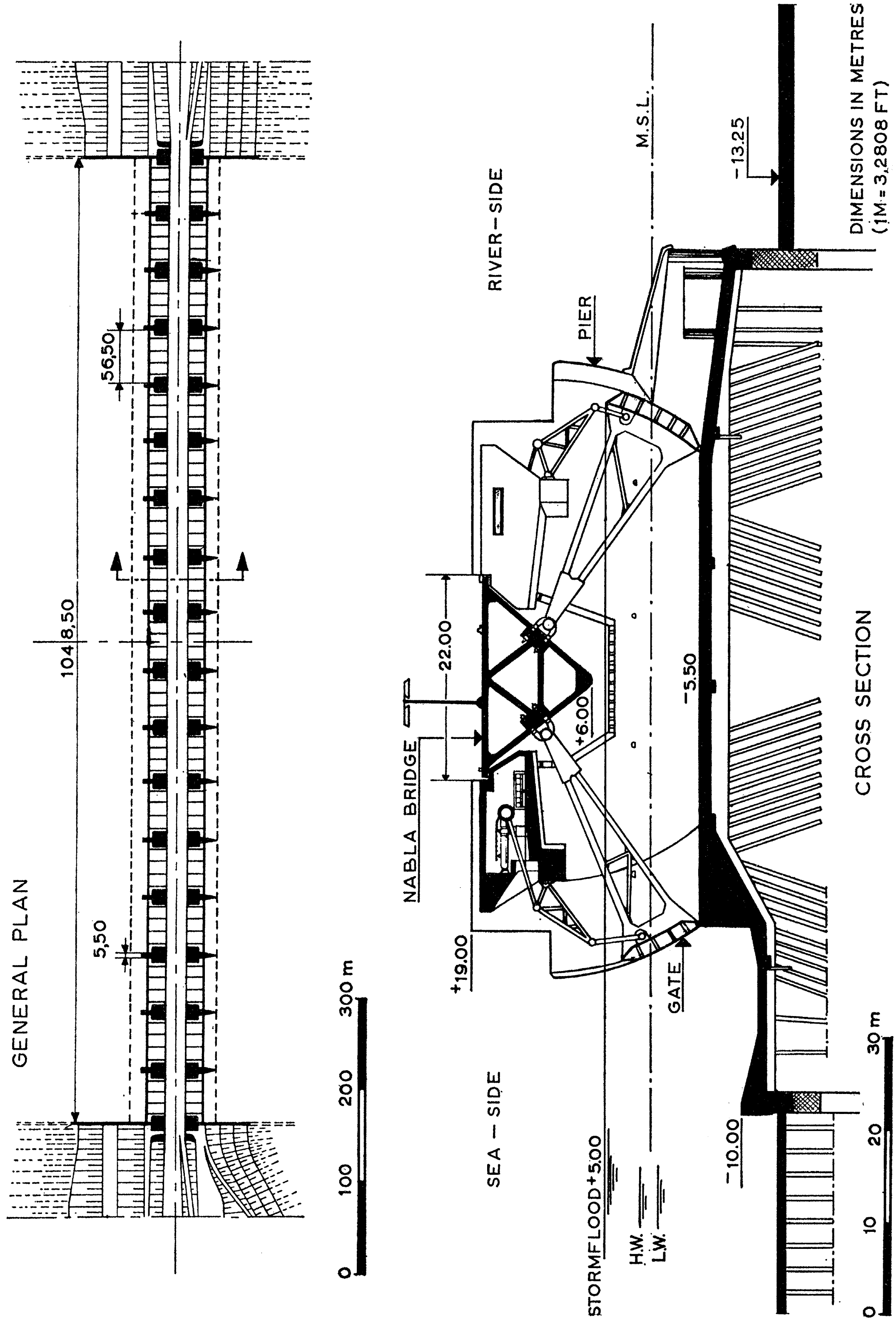

FIGURE 13. Discharging sluices in the Haringvliet estuary.

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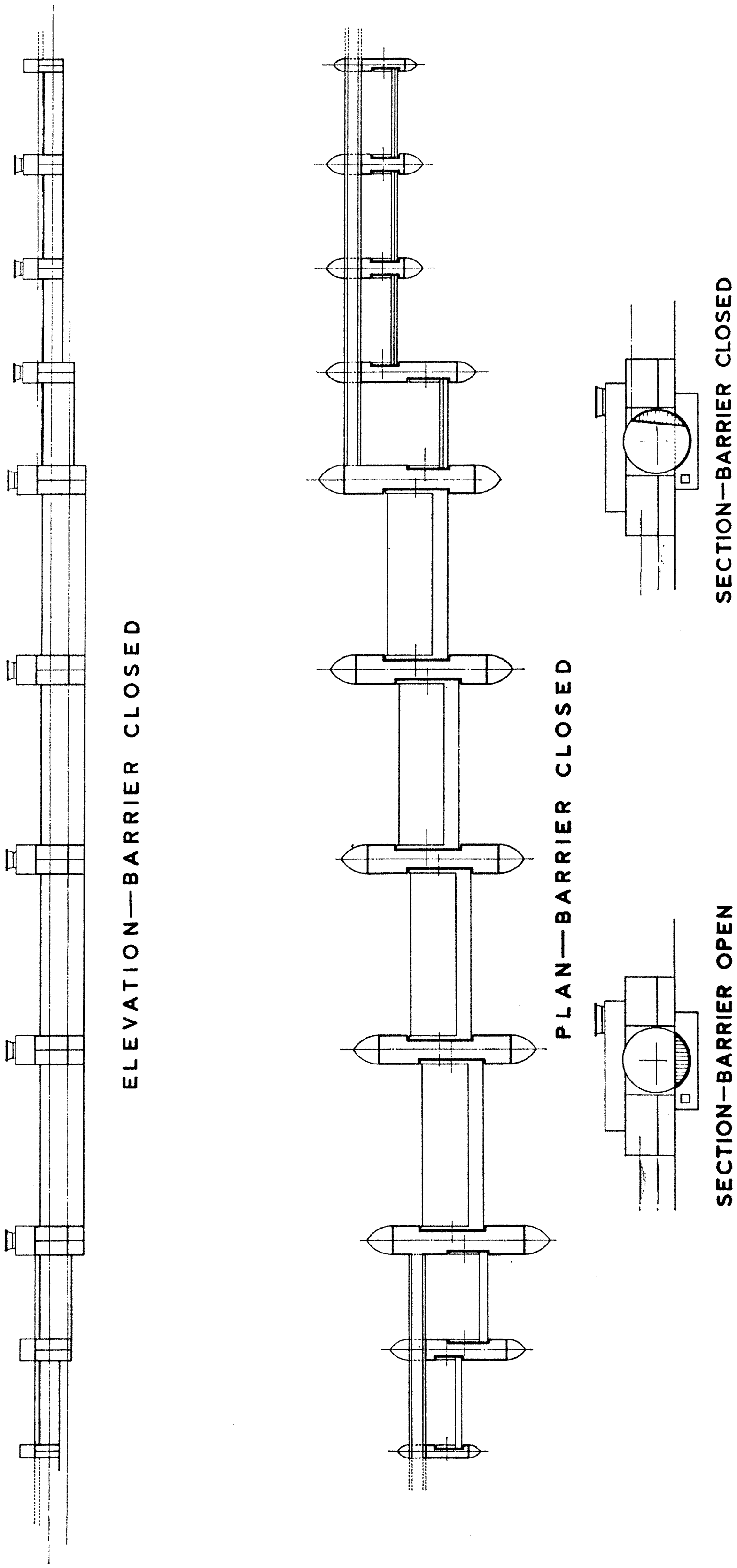

FIGURE 14. Segment gate type barrier.

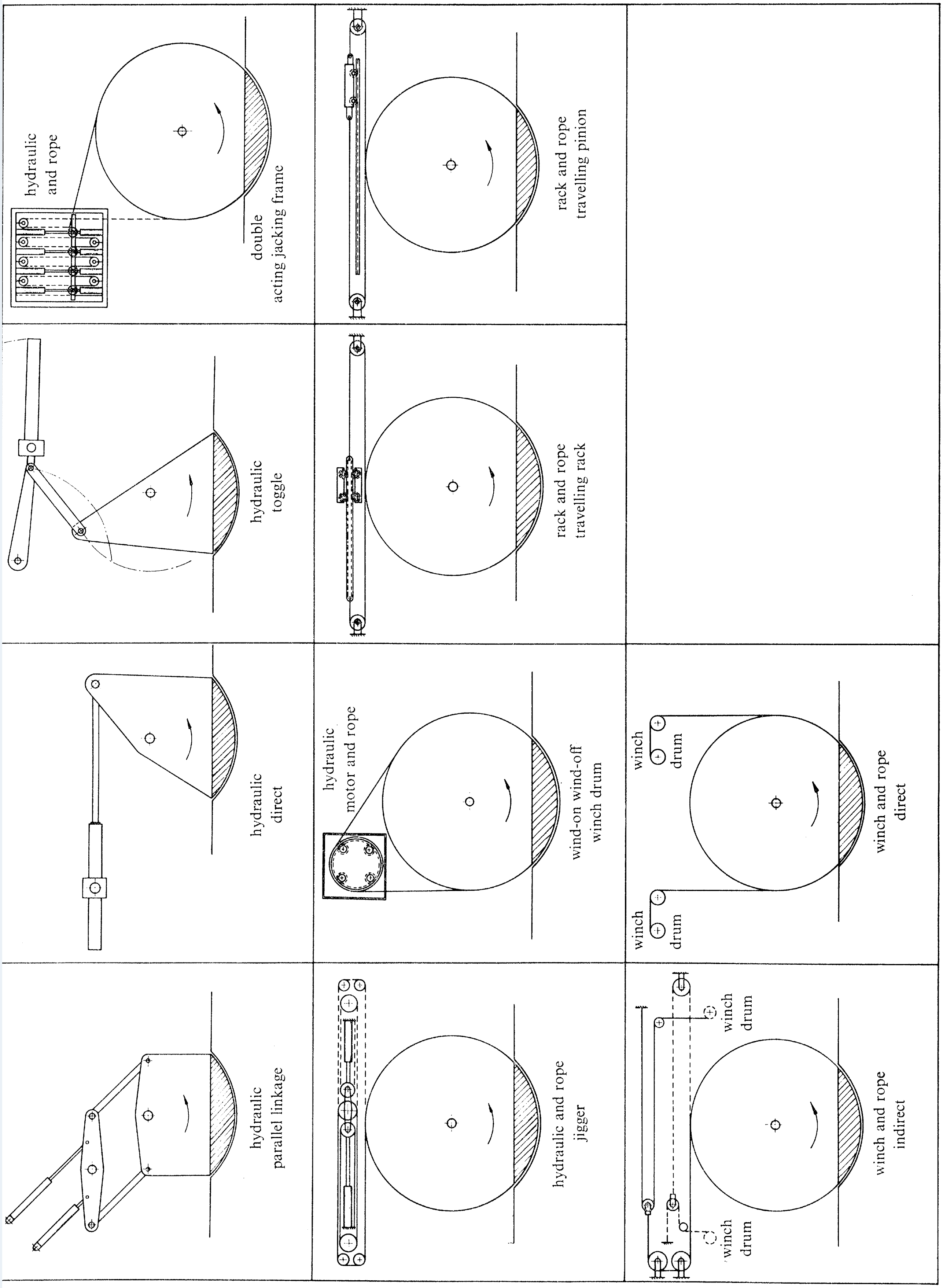

FIGURE 15. Alternative mechanisms of operating segment gates under study.

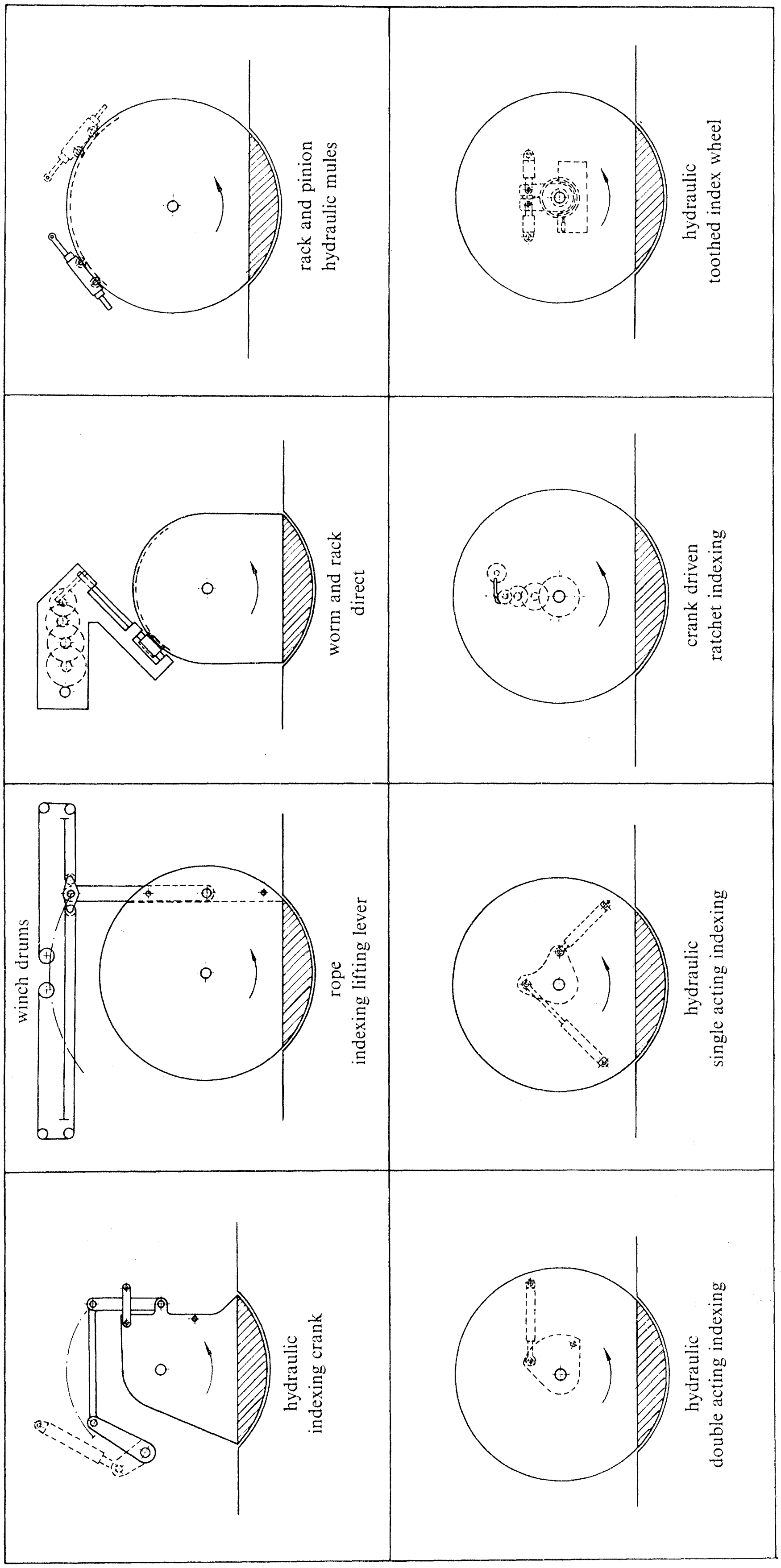

FIGURE 16. Schemes in which mechanism can be totally enclosed.

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left shows how the segment would be moved through 90° to make the barrier effective in arresting river movement.

Horner's figure 5 (this volume, p. 184) gives an artist's impression of a rising sector gate at Woolwich. It is thought by this method a barrier could be constructed with a minimum of visual obstruction.

On the matter of reliability in operation, the segment gate comprises a single moving part which, freed from restraint would, by balance and buoyancy, adopt the closed position. Mechanism for its control and reinstatement in the open position is of course necessary. A number of alternatives have been considered with a view to ensuring that the mechanism will be as reliable as possible.

We have examined some 18 different methods of operation, all of which have been designed to a stage which allows assessment of reliability. All are reliable, but some are more reliable than others. We are currently attempting to make a comparison of reliability, but this is difficult in a form of structure of such magnitude, as nothing has yet been built like it, and there is of course no practical experience on which to draw. Special facilities whereby all mechanism can be easily disengaged, thus allowing the gate to move under gravity into its closed position, are under close study. They include counter-weighting, built-in buoyancy and hydrostatic bearings to minimize resistance to turning of the supporting shaft under its very high loading of some 40 MN (4000 tons force). Other considerations of vibration, damage resulting from shipping collision, easy replacement of components and back-up systems, have yet to be fully explored, and if possible brought into a statistical analysis.

Figure 15 shows the wide range of alternative mechanisms under study which fall into two groups, namely, winch and wire, or hydraulic ram with machinery accommodated either totally inside the pier or partially external.

Figure 16 shows schemes in which mechanism can be totally enclosed. To my mind a sufficiently reliable system can be developed on the lines of the right-hand bottom diagram, the 'hydraulic toothed index wheel'. It envisages the segment gate in the form of a torsionally rigid member like the crank shaft of a single cylinder engine but having a sector for the crank pin. Support would be by a single hydrostatic bearing at each end. Such bearings offer negligible resistance to rotation or end-wise shaft movement and can be designed to accommodate mis-alinements. The shaft extension within each pier would carry a large tooth-edged disk within the embrace of a disk-brake system. Rotation of the segment would be accomplished by twin hydraulic rams operating a slipper free to rotate on the shaft extensions, but engageable by cotter with the toothing on the disk. With such a system, exceptional turning movement can be applied at will, but, more important in an emergency, all mechanisms can be disengaged and the gate held by the disc brakes until such time as closure is called for. Closure would be accomplished by gravity upon the release of fluid pressure on the disk brakes.

Of course a system of mechanically operated gates can never be as reliable for flood prevention as the raising of river banks, and the problem remains to weigh the risk against the saving of cost, and considerations of amenity associated with the raising of river banks.

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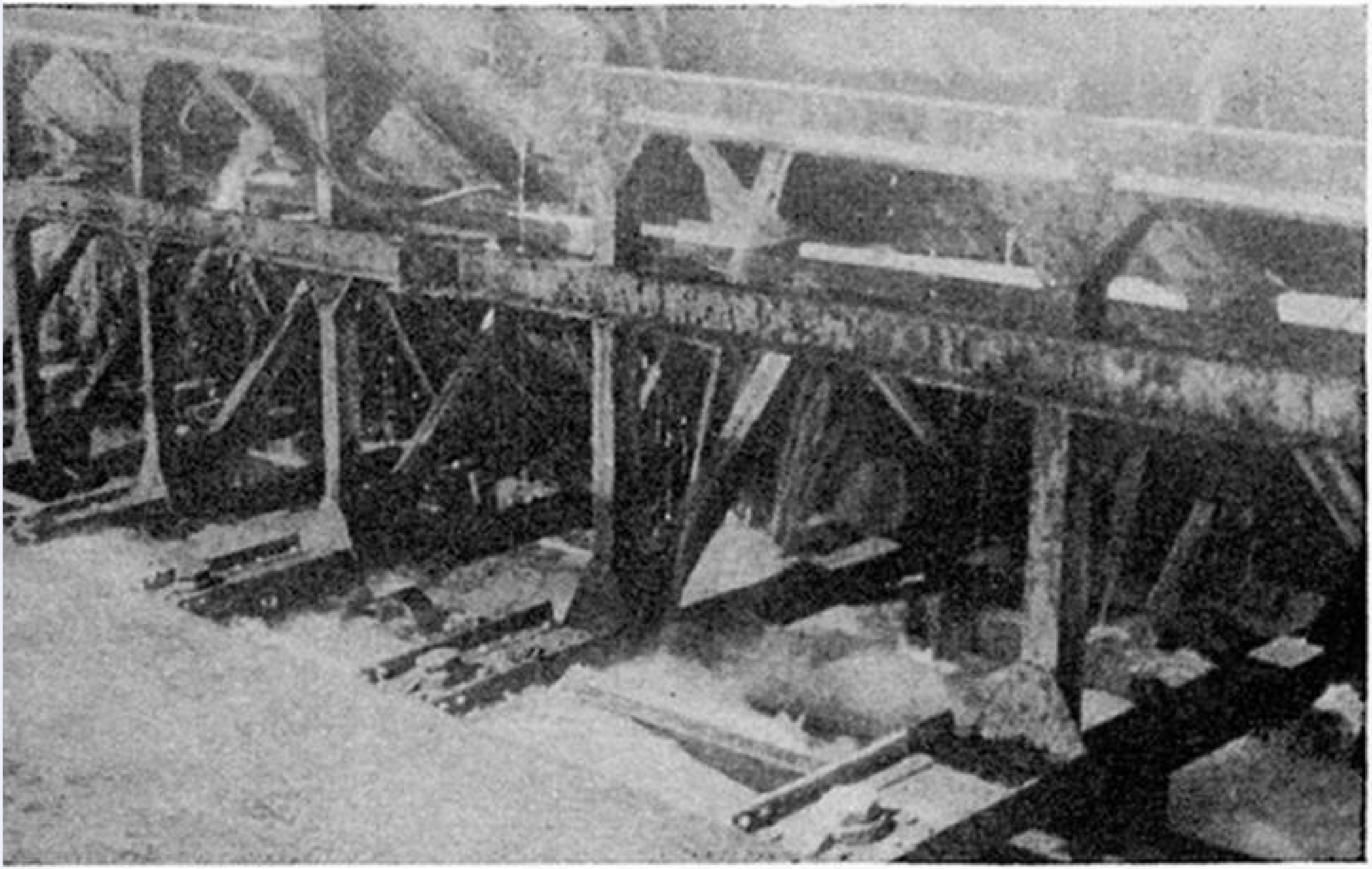

FIGURE 5. Close up of frames.

FIGURE 6. Dethridge weir in operation.

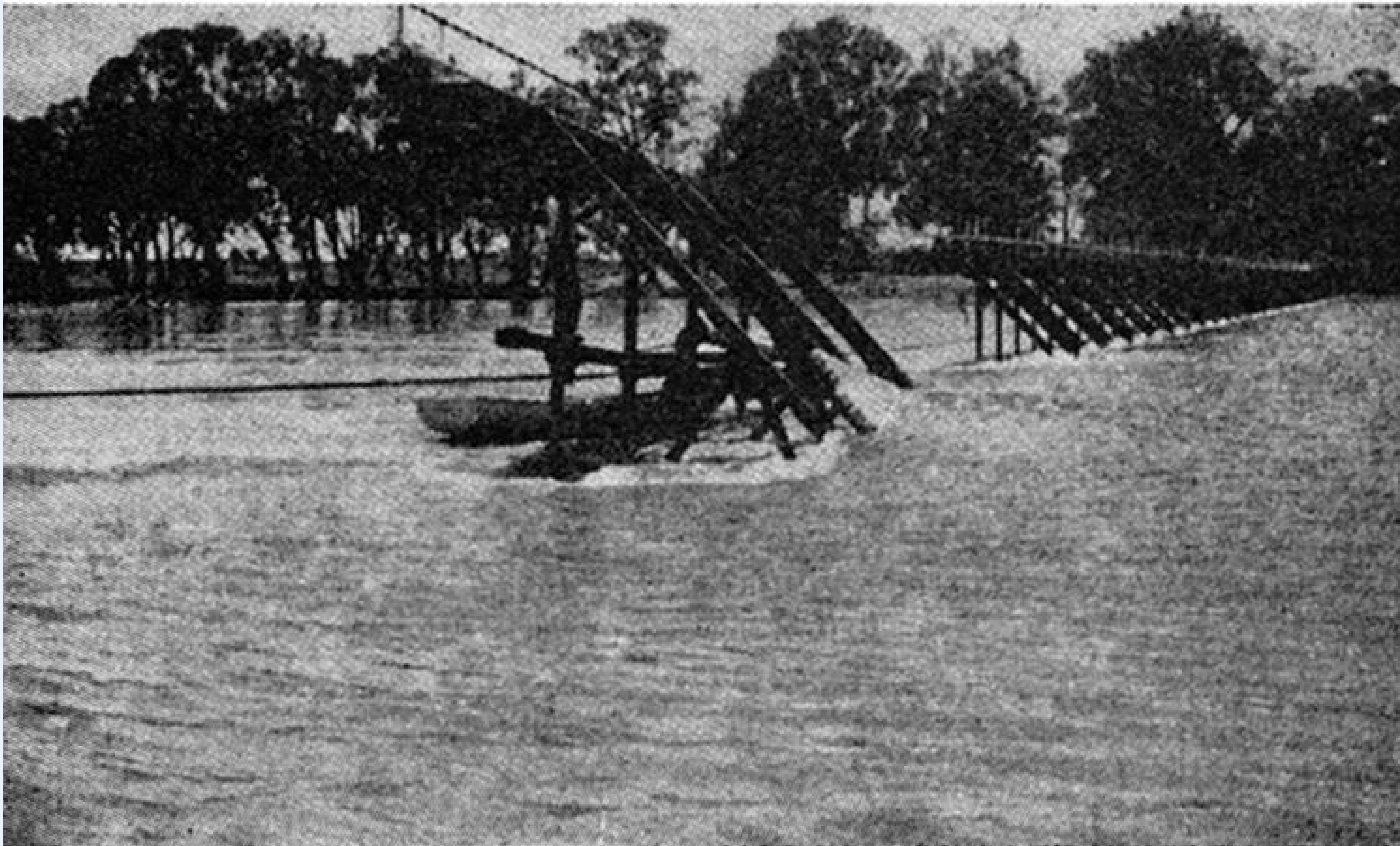

FIGURE 7. Mildura weir trestle unit moving into position in the river.

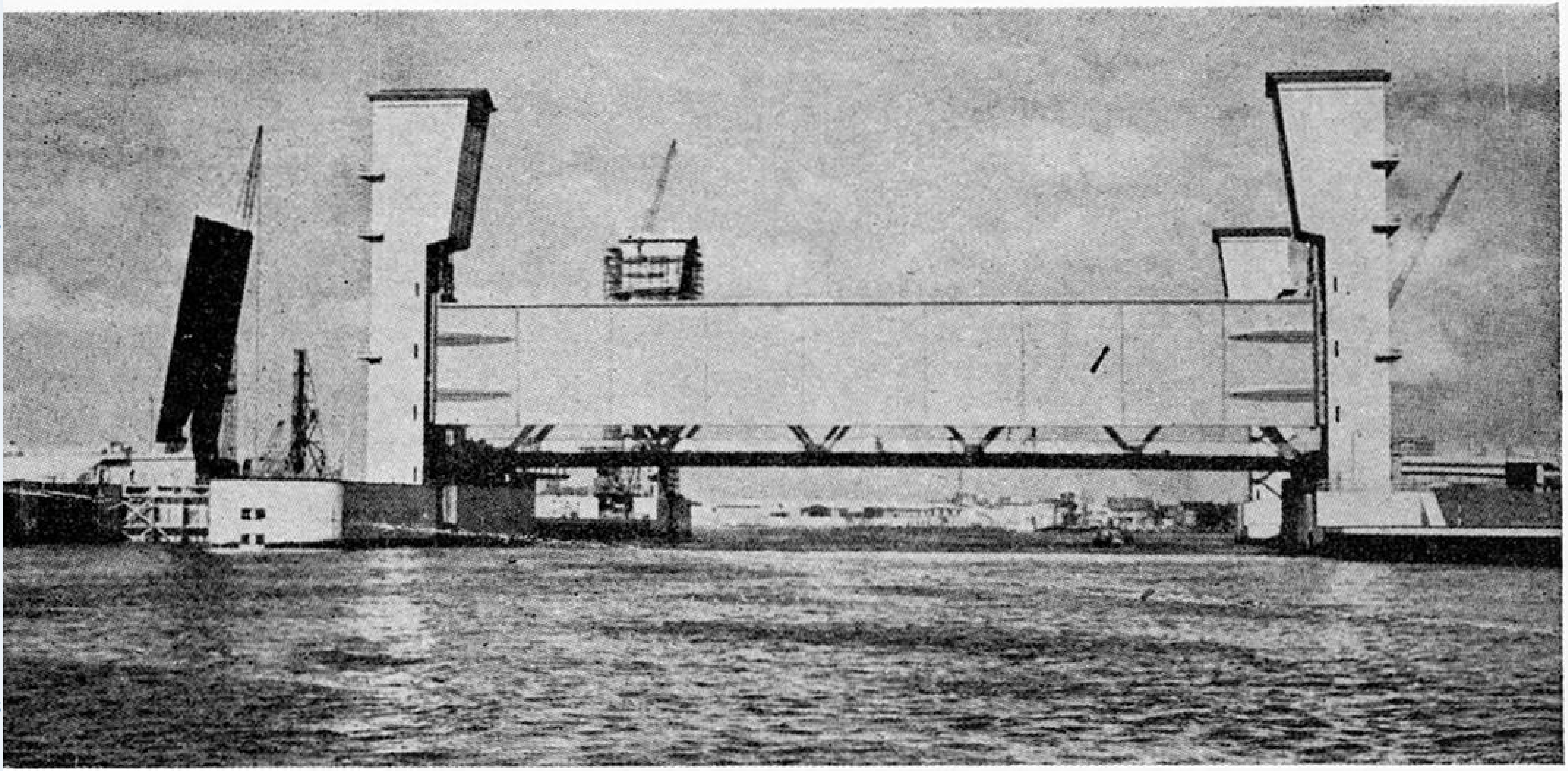

FIGURE 8. Storm weir and lock at Krimpen, Holland, across the river Ijssel.

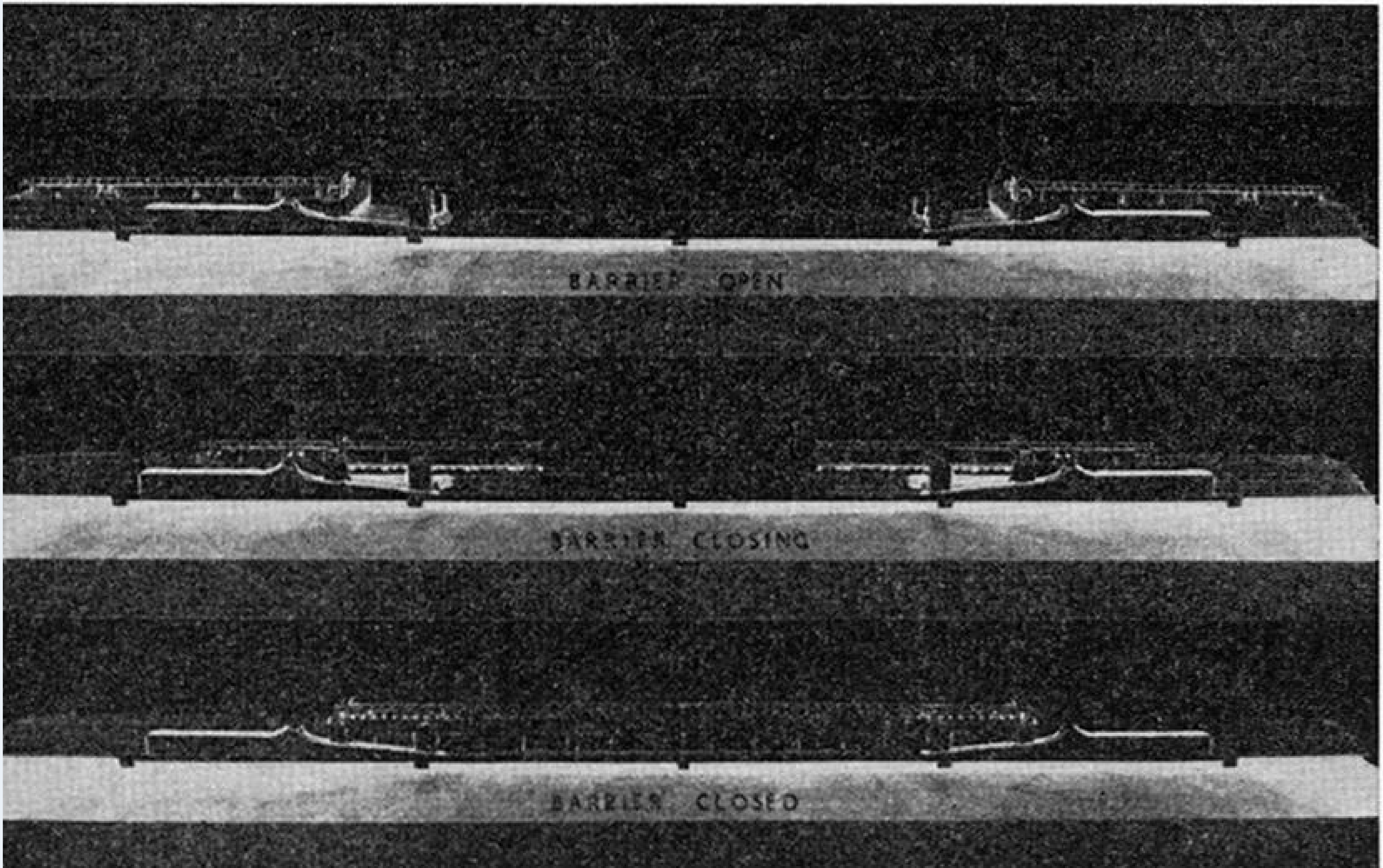

FIGURE 12. Operation of retractable barriers.