The steel structures of the hydro-electric plant at Wettingen

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The Steel Structures of the Hydro-Electric Plant at Wettingen.

Die Stahlkonstruktionen des Limmatwerkes Wettingen.

Les constructions métalliques de l'usine hydro-électrique de Wettingen.

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1. Constructional Details.

The Limmat Power Station at Wettingen, 20 km below the point where the river leaves the Lake of Zurich, supplies electric power for the City of Zurich. It is one of the latest constructions of its type in Switzerland and was completed in 1933. The fall of the River Limmat is utilised by means of artificial damming, a solid barrage being combined with the actual power station in the river itself. As shown in Figs. 1 and 2, movable sluice gates are constructed in and above the solid barrage to cope with flood water. The barrage is of the articulated type, having interior hollows and four sluices. The latter are each 11 m wide, with intermediate piers 5 m in width having double-closing bottom outlets. These outlets, which close to a permissible leakage of 50 l/sec., are each provided upstream with a sliding sluice of 2.8 m and downstream with a segmental sluice of 2.5 m clear height. The maximum statical water pressure at sill level is equivalent to a head of 19.5 m. At its crown the barrage is provided with 4 automatic overflow traps, 2.5 m high, which serve for the fine regulation of surface level. Under normal working conditions the turbines and overflow traps together can cope with the average quantity of water brought down, so that it is only very seldom that the bottom sluices must be opened. The upstream sliding sluices form the closing device proper, while the rear segmental sluices serve to regulate the effective flow. Consequently, the sliding sluices operate permanently either entirely closed or fully open. In the latter case they are raised at least 1 m above the upper edge of the opening, so that they are not affected by hydro-dynamic influences.

The two bottom sluices are operated by seperate lifting gear. The mechanism for the sliding sluices is situated in the control cabins on the top of the barrage; that for the segmental sluices in the chambers inside it. The operating gear for the segmental sluices is designed for a full one-sided water pressure of 19.5 m, that of the sliding sluices is designed to operate at a one-sided water-head pressure of only 5 m. The reduction of the static pressure of 19.5 m head of water acting upon the closed sliding sluices to the pressure of 5 m at which the sliding sluices are designed to operate, in effected by pressure release pipes leading to the chamber between the two sluices. The valves of these pipes are situated in the same hollow chamber as the lifting gear of the segmental

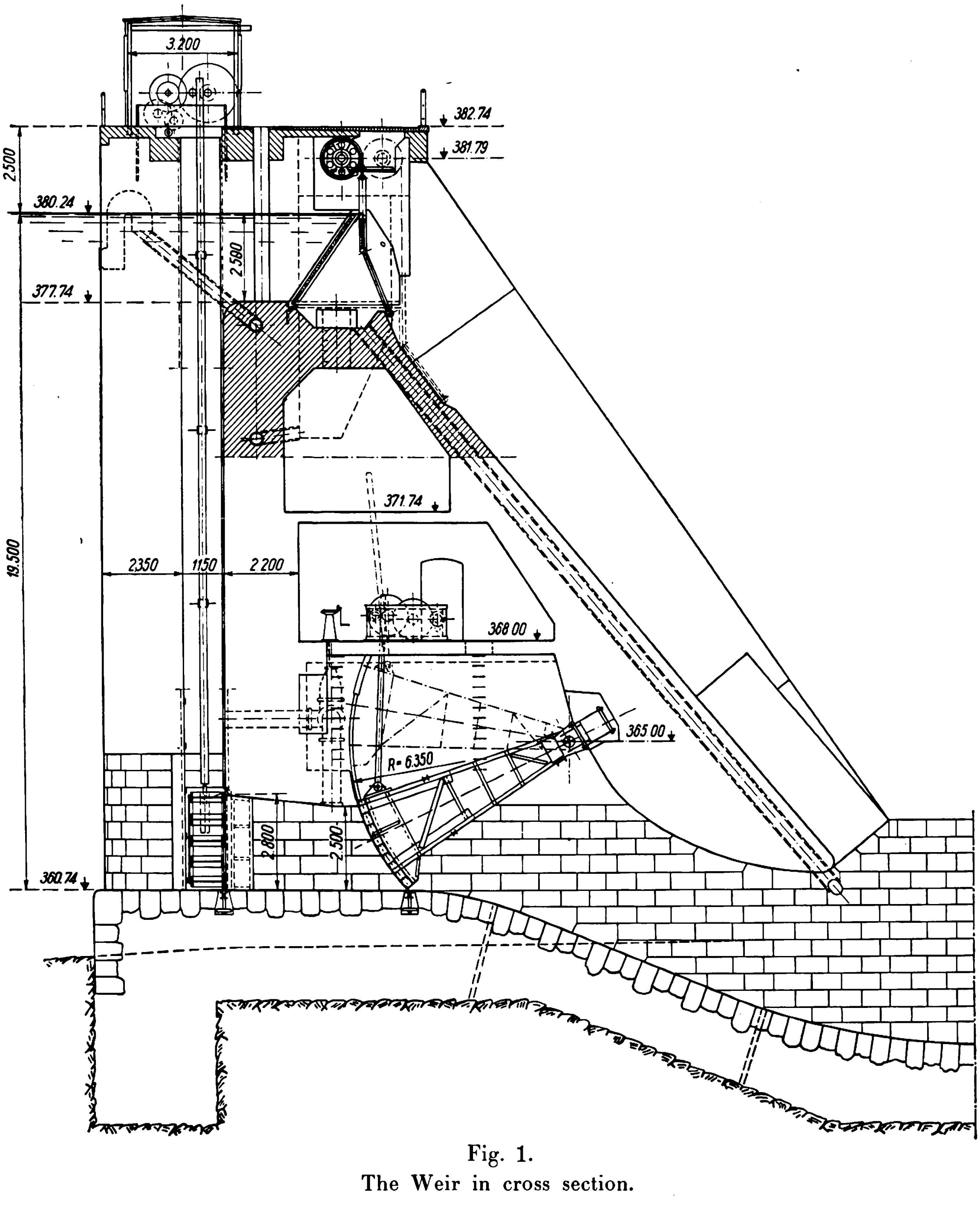

Fig. 1.
The Weir in cross section.

sluices. Water level in this chamber is constantly controlled by means of a Piezometer while the lifting gears are being operated. Complete equalisation of pressure was avoided so that the sliding sluices cannot lift away from their closures and permit the entrance of small floating particles between sluice and closure frame. Lifting gear constructed to operate at 5 m overpressure has to be comparatively sturdy. The lifting speed of the sliding sluices with electrical drive amounts to 0.2 m per minute, and with emergency drive (4 men per sluice) 0.55 m an hour. The segmental sluices, which have consequently to be operated under the full one-sided water pressure of 19.5 m, are equipped with extremely powerful lifting gear with lifting speeds of 0.5 m per minute when electrically driven and 0.7 m per hour with emergency drive (2 men per sluice).

The segmental sluices as well as the downstream faces of the closed sliding sluices are accessible via shafts leading from the middle deck of the barrage, so that the functioning of all movable parts, and above all the watertight closures can be inspected at any time. The overflow traps on the top of the barrage serving to effect more delicate surface regulations can effect automatic adjustments of + 2 cm and — 0 cm. We shall now proceed to examine the sluice valves of this rather unusual structure, which reveal some new and interesting departures in the construction of watertight closures.

2. *Watertight valves of the bottom outlets.*

The sliding sluices, of which Fig. 3 shows cross section, suspension, and support in the grooves, protrude on both sides into the separating piers, and in these grooves are situated the devices for supporting them and effecting a watertight closure. The body of the sluice, 11.4 m wide, consists of five rolled broad-flange girders which on the upstream side carry a skin of steel plating

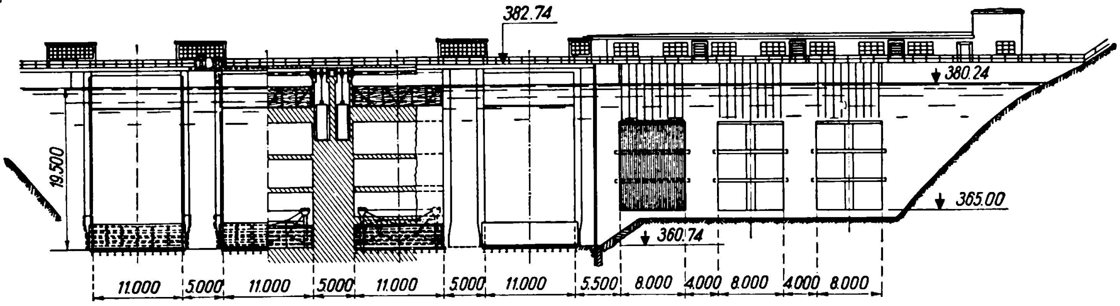

Fig. 2.
View and longitudinal section of Weir.

12.1 mm thick and which are connected by vertical solid webbed braces and by the lateral girders fitting into the grooves, to form a rigid unit. The flange of the bottom girder is situated 12 cm above the lower edge of the sluice gate — suffliciently high to obviate blocking of this opening from upstream and the consequent underpressure that would interfere with the movement of the sluice gate. Both top and bottom girders are additionally stiffened by ribs welded on between the braces on account of the direct vertical water load. Both girders fitting into the grooves transmit the water pressure to the lateral guides of the grooves by means of interchangeable bronze edging affixed to the sluice gates. These slide on the smoothly machined steel lining of the grooves, which can also be interchanged. The upper watertight closure is similarly designed. The closure at the sill of the sluice comprises a smooth steel edging affixed to the gate; the effective breadth of its edge is 25 mm, which contacts with the steel-reinforced sill as seen in Fig. 4. In order to obtain close grouting of the sill, the necessary holes were bored and cement mortar pressed in. These holes were then sealed with threaded plugs. All the other borings carried out for bolting were also subsequently filled up with lead, so that a smooth contact surface was given to the sill. By placing the upper girder in contact with the top closure deformation of this girder was obviated and a really watertight closure obtained. The lower main girders, on the other hand, are gradually deformed by the high water pressure, so that at the sill it was necessary to provide additonal closure in the form of an interchangeable hollow rod, as shown in Fig. 4. This, with its loose seating and ability to deform, presses tightly against the bottom edge of the sluice gate and the body of the sill, thus forming a closure which practical experience has proved to be perfectly watertight.

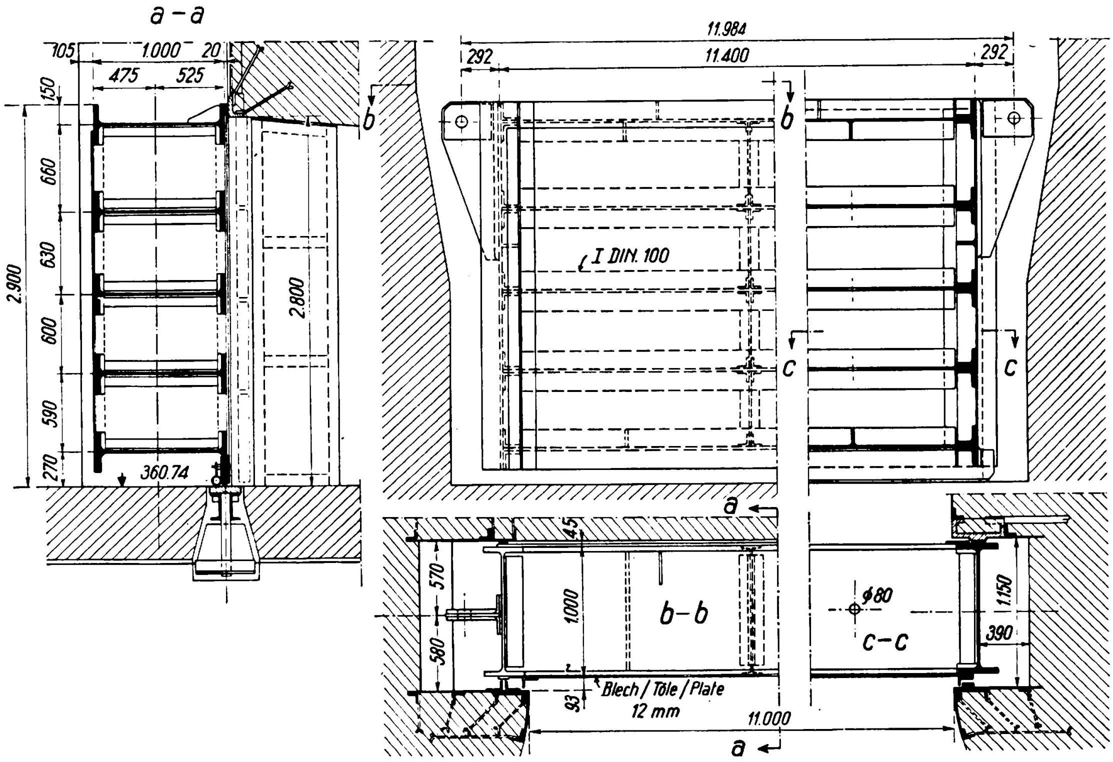

Fig. 3.
Sliding sluice.

The sluice gate is suspended in the gravity plane by means of two racks working in brackets situated entirely in the grooves and therefore out of reach of the force of the water rushing through the openings. The racks are divided into sections and can be removed when the sluice gate is completely drawn up for revision. The groove linings consist of cast steel rails in the region where they contact with the closed sluice gate, while their upper portion right to the top is of [-rails of lighter quality, overlaid with smooth steel plating, for here the gate moves under approximate equalisation of pressure. The upstream groove rails are similarly designed: here the sliding elements comprise the groove lining and the angle of the sluice gate edge. These angles, which recede slightly towards the grooves, also prevent floating objects from being drawn into the grooves. In the vicinity of the grooves the piers are reinforced with 12 mm thick interchangeable steel plates, while the interior of the grooves is lined with granite.

The sliding sluices are dimensioned for a static pressure of a 20 m head of water, in accordance with the Swiss Federal Regulations for Steel Structures.

The material used was Steel 37 with a yield stress limit of minimum 0.6 of the tensile strength; in the rails and watertight closures bronze, cast steel and special castings were employed. The lifting forces were calculated on the weight of the sluice gates minus upthrust, the weight of the racks, the water load on the upper closure edges (2 cm wide at 5 m overpressure), the weight of water on the sill closure (width 2.5 cm, overpressure 19.5 m), the frictional resistances based on a coefficient of friction of 0.35, giving a lifting force of 100 t in each opening. The closing power of the sluice gates was calculated on the frictional resistances as above, minus the dead weight of the gate and racks, less upthrust. In this manner a closing power of 30 tons was obtained for each opening, and the racks are designed to withstand a buckling force of this amount.

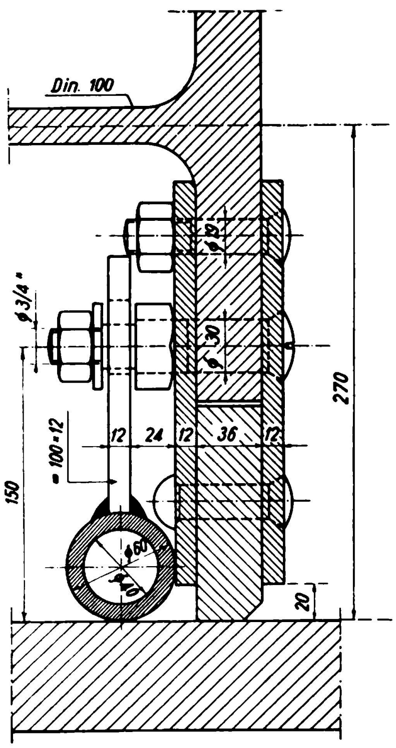

Fig. 4.
Watertight closure between gate and sill of sliding sluice

3. Regulation sluices of the bottom outlets.

The regulation sluices of the bottom outlets are designed as segmental sluices. They give an upstream closure at the same level and on the same constructional principle as the sliding sluices. They are pivoted at level 365.0. As shown in Fig. 5, these segmental sluices are constructed of two two-hinged girders with tie carried by the king pin bearing. The two pivoting walls, forming component parts of the two-hinged girders, together with the intermediate internal points of intersection of the latter carry transverse plate girders, which in turn carry the curved steel plating via a system of longitudinal girders. The tie member releases the king pin bearing from horizontal thrust. The two external pivoted walls were placed one meter back from aperture of the outlet to render the sluices and their closures easy of access. In consideration of the amount of water passing through under the pressure of a 19.5 m head, the segmental sluice was calculated on hydraulic dynamic efforts. All the bolts or nuts that have to be loosened or replaced are made of bronze. The sluice gate is suspended from the bracket-like projections of the transverse girders in the plane of the pivoted walls (Fig. 1).

The closure of the lower edge of the gate with the sill surface is effected by means of accurately machined cast steel edging fitted into the gate. The closure

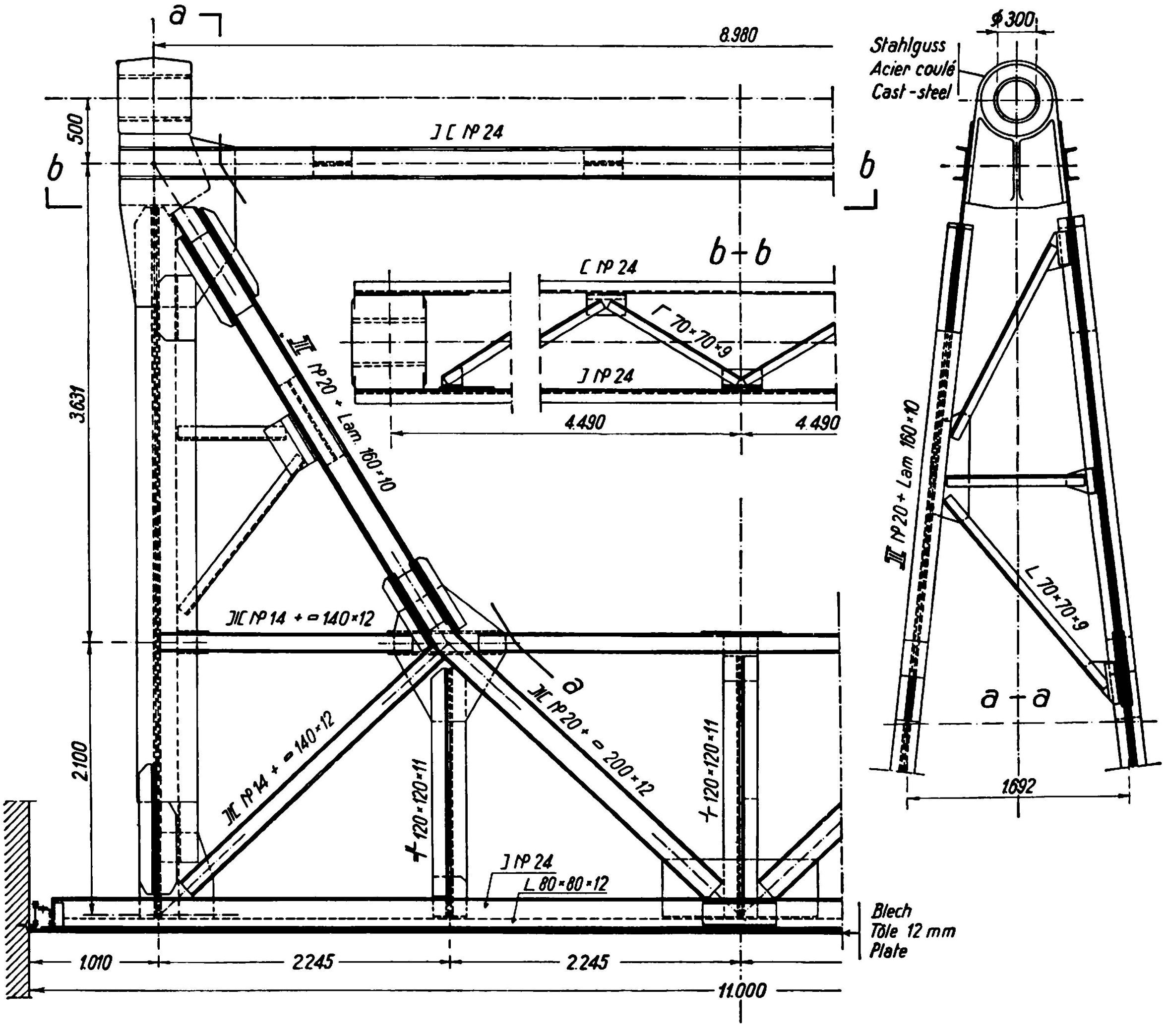

Fig. 5.
Steelwork of segmental sluice.

surfaces are restricted to 40 mm, in order to minimise any water pressure from below that might offer resistance to the closing of the sluice. As the total water pressure on this knife-edge just before the gate closes is entirely converted into speed, this pressure may be calculated as nil.

The lateral closures (Fig. 6) consist of spring steel plating of high strength. The thickness is 3 mm, and they are movably fastened to the binding angles of the gate. Their free ends are provided with angle reinforcement, which in turn carries the surface closure. In order to ensure closer fitting with the closure guides cemented into the walls of the piers, this edging is made in

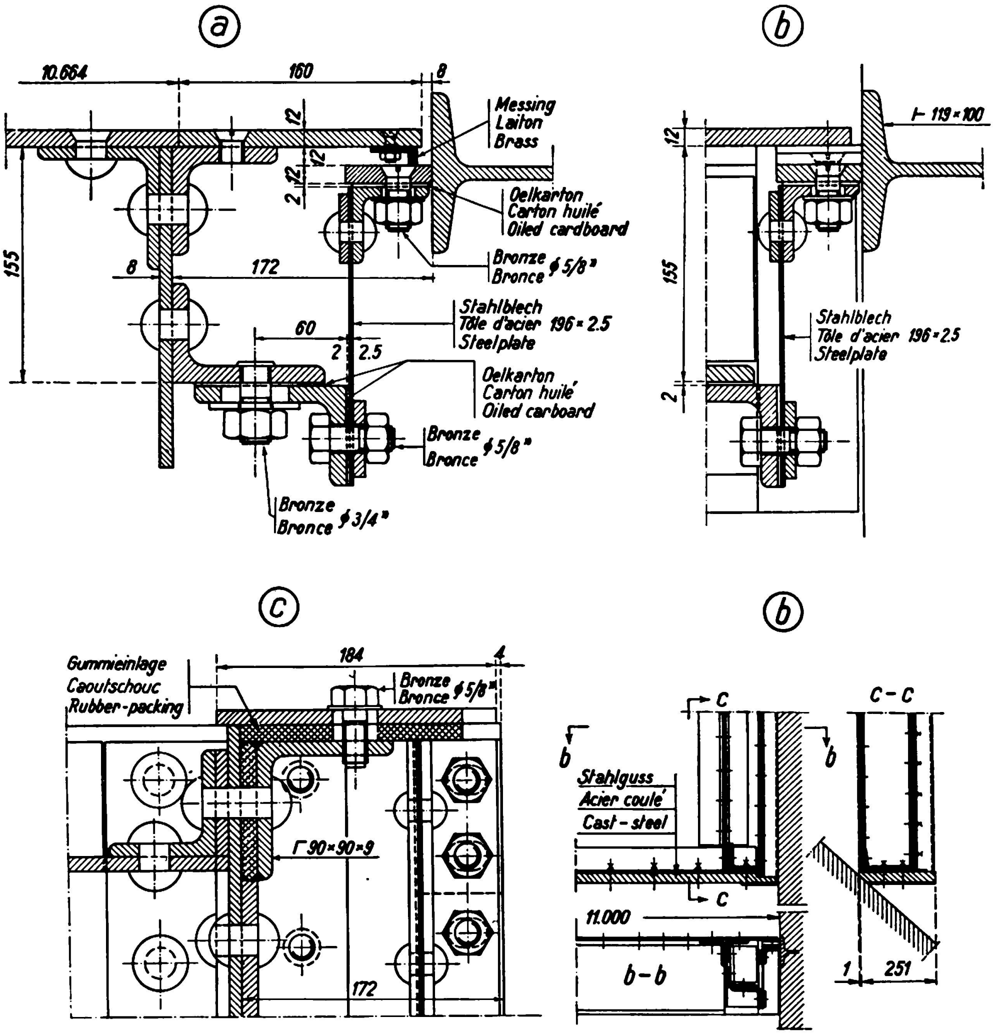

Fig. 6.

Closure of segmental sluice, shown in detail.

a) Normal lateral closure.

b) Transition from lateral to sill closure.

c) Transition from lateral to bottom edge closure (on sluice gate).

60 cm lengths and accurately machined. It fits into correspondingly planed guides in the walls of the piers. These fixed guides in the pier walls are continued upwards to a height prescribed by the necessity of resisting the water pressure on the lateral walls. The lateral closure edging is pressed up stream by the pressure of the water against the guides, the head of water in the lower part of the lateral closures entering the space between spring steel and the outermost cross girder over a length of about 10 cm. In order to prevent the water above from escaping unrestrictedly, the space referred to is closed with a compressible rubber plate and superimposed steel plating (Fig. 6). To prevent escape of the water under head pressure in the space between the outermost girder and the steel plating of the closure at the sides — over the top closure — angled brass edging is inserted between the steel plating of the gate and the fixed closure edging. The top closure (Fig. 7) consists of a tube fitting into the slot under pressure of the water. The steel casting forming the

guide for the tube is fastened to a continuous anchor iron at the head of the aperture. The top closure is so high that it comes above the upper edge of the aperture and is not affected by the rushing of the water. The entry of the water from upstream is effected by openings arranged in the upstream face of this casting and protected from impurities by copper wire gauze. In addition, the tube is also held in position by brass springs. This arrangement ensures that it is drawn surely in the direction of the fall of potential of the water and into the fissure it is designed to close. When testing the segmental sluice with these carefully constructed closures the permissible leakage of 50 l/sec. was therefore not reached.

By means of the two-hinged girders and their partial action as pivoted walls the water pressure on the segmental sluice, is transmitted to two king pin bearings situated 9 m apart and with a bearing capacity of 300 tons (Fig. 5).

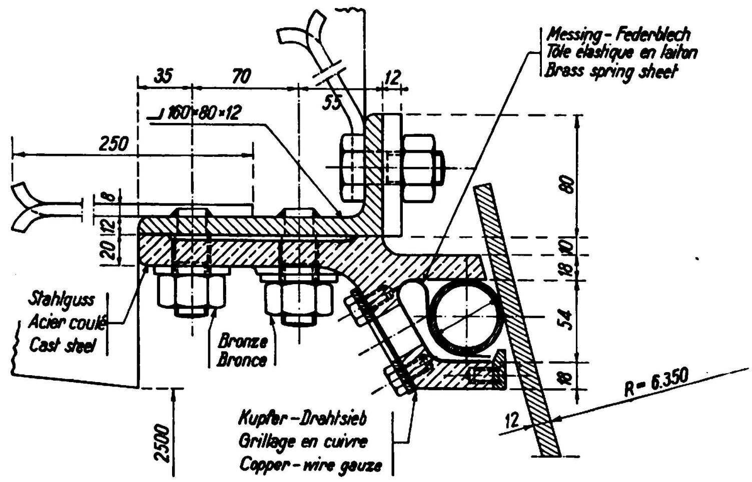

Fig. 7.
Closure at bottom edge of segmental sluice.

These cast steel bodies, with pin hinges of SM Steel secured against turning, are set in bronze bushes of 20 mm thickness and provided with Tecalemite-Grease pressure lubrication. The specific pressure in the bearings for the slow movement involved is maximum 165 kg/cm^2, a figure which was based on many years' experience.

The segmental sluice was assembled and bolted on scaffolding, after which the bearings were placed in their final position and grouted. Only then was the sluice gate riveted and, simultaneously, the lifting gear was erected so that the gate could subsequently be operated. When the segmental sluice had been installed and made movable, the closures were inserted in the following order: bottom, side and top. In order to fit the lateral closures accurately, their guides anchored in the masonry were first screwed on to the sluice gate and only grouted after their positions were accurately determined. The top closure was also temporarily affixed to the gate with its cast steel fittings, the gate lifted and after its passage every part examined for accurate fit. Only then were the fixed elements of the top closure grouted.

When calculating the steelwork of the structure the Swiss Federal Regulations were adhered to. The lifting forces were determined from the turning moments composed of dead weight, and friction at the bearings, top and side closures, these aggregate turning moments being equivalent to the lifting force multiplied by the leverage of the rack. To this was added 25% as a precautionary margin for resistances, giving a lifting force of 30 tons per opening. The amount of force required for closing the gates was ascertained from the turning moment consisting of dead weight, from which the turning moments of bearing friction opposed to the action of closing, the friction at top and side closures and the water pressure from below, acting with 20% of its full value on the sill closure

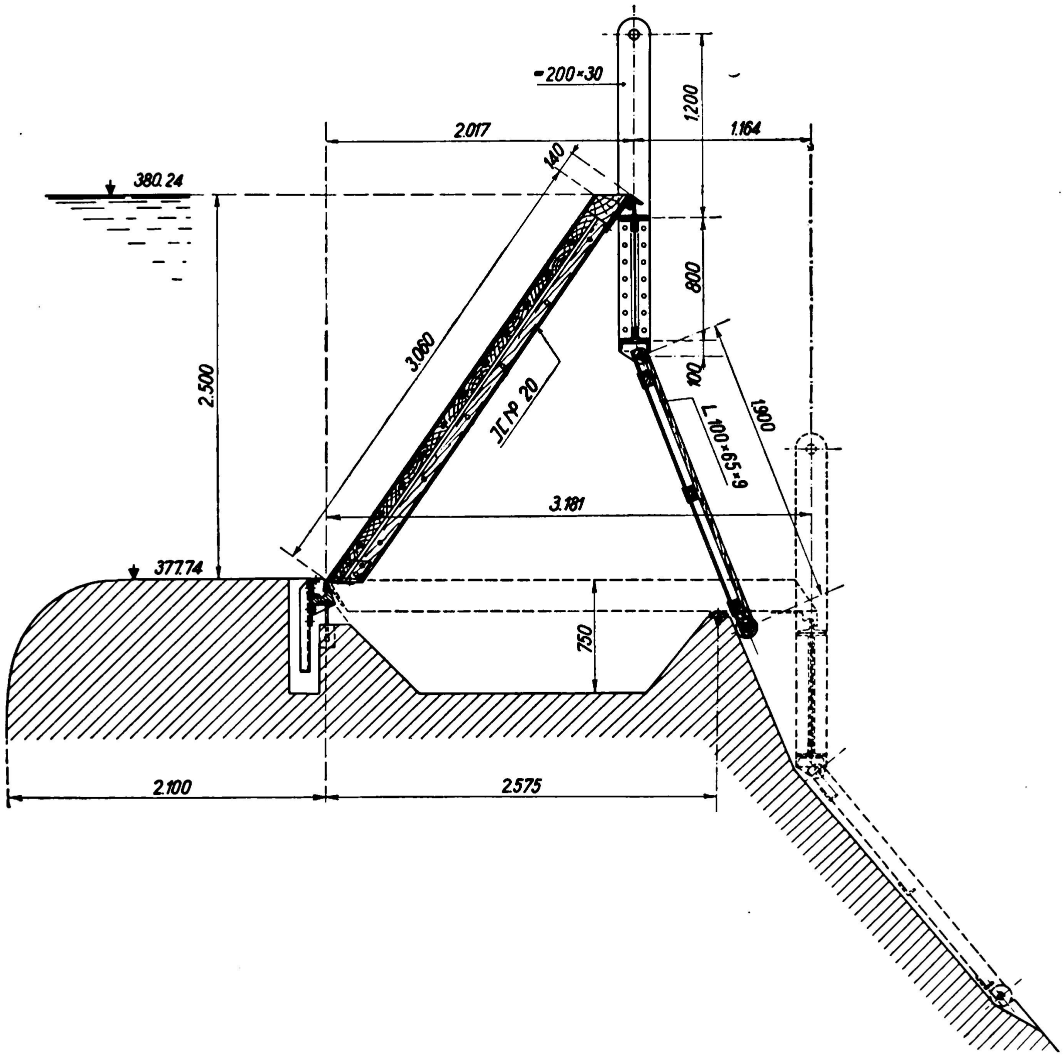

Fig. 8.
Section through overflow trap.

were deducted. By assuming equality with the closing force multiplied by the leverage of the rack, a downward thrust of 4 tons was obtained. Although the rack thus remained subject to tension, it was designed to withstand buckling. The top closure is calculated for a water pressure of 17.0 m head, the spring steel plates of the lateral closures, with a width of 16 cm, for a mean head pressure of 18.5 m. The coefficients of friction are assumed as 0.40 for the top closure, 0.30 for the planed lateral closures, the latter value also taken for pin friction under negligence of the lubricating effects.

4. Automatic overflow traps for fine surface regulation.

The overflow traps, System Hubert & Lutz, Zurich, are self-acting for hydrostatic pressure on the traps. The traps rest on knife-edge bearings situated on the top-sill of the barrage. At the top they are also supported by knife edges on a girder, the ends of the latter being affixed to straps attached to Gall-chains which are rolled up on chain drums. The drums are carried on a tube passing across the openings. The counterweights are housed in shafts situated in the piers of the barrage. When the traps move the rollers roll forward on rails anchored in the side walls, slipping being prevented by a rack guide. The

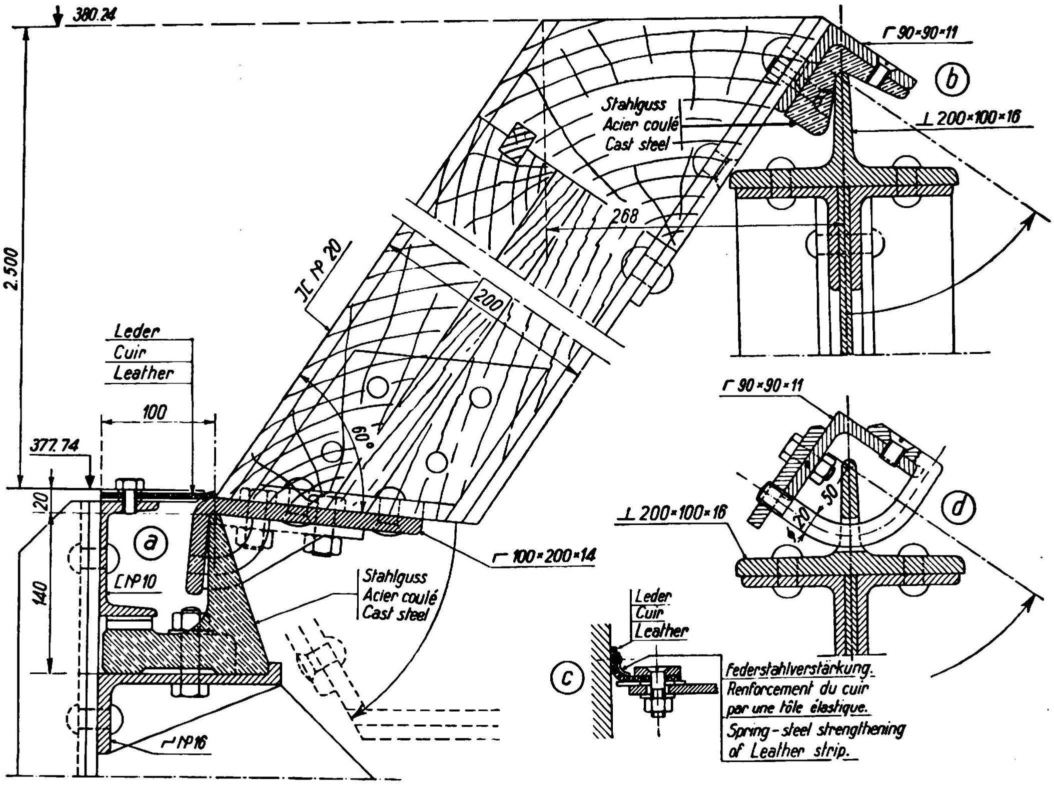

Fig. 9.

Overflow trap closure, shown in detail.
a) Lower knife-edge bearing.
b) Upper knife-edge bearing.
c) Lateral closure against pier.
d) Safety arrangement against lifting.

torsion strength of the rollers ensures a perfectly uniform movement of the trap, even if it has to operate under unequally distributed loading. In the construction illustrated in Fig. 8 the girders on the upstream side of the trap are overlaid with wood which is constantly kept either wet or at least under easy flow of water, so that it cannot dry out or crack. On the lower side of the supporting full-web girder is suspended a protecting apron composed of a steel skeleton covered with planking; its lower end is free to descend on rollers on the downstream face of the barrage crown. Thus a space isolated from the temperature of the outside air is formed below each trap, so that even at very low temperatures there is no danger of the trap bearings becoming iced.

This has been proved by experience. If desired, this chamber can be heated by warm air fed from the machine room.

The knife-edge bearings of the trap on the sill of the barrage and on the supporting girder (Fig. 9) reduce undesirable frictional resistances to a minimum. The closure of the trap along its pivot axis and at the sides is rendered almost completely watertight with the aid of leather strips reinforced with steel plating. The leakage is collected in a chute passing below the trap and taken off at the sides by pipes, so that the downstream face of the crown of the barrage is kept dry when the trap is closed. The side walls of each aperture, which contain the counterweight shafts, are covered with removable steel plating.

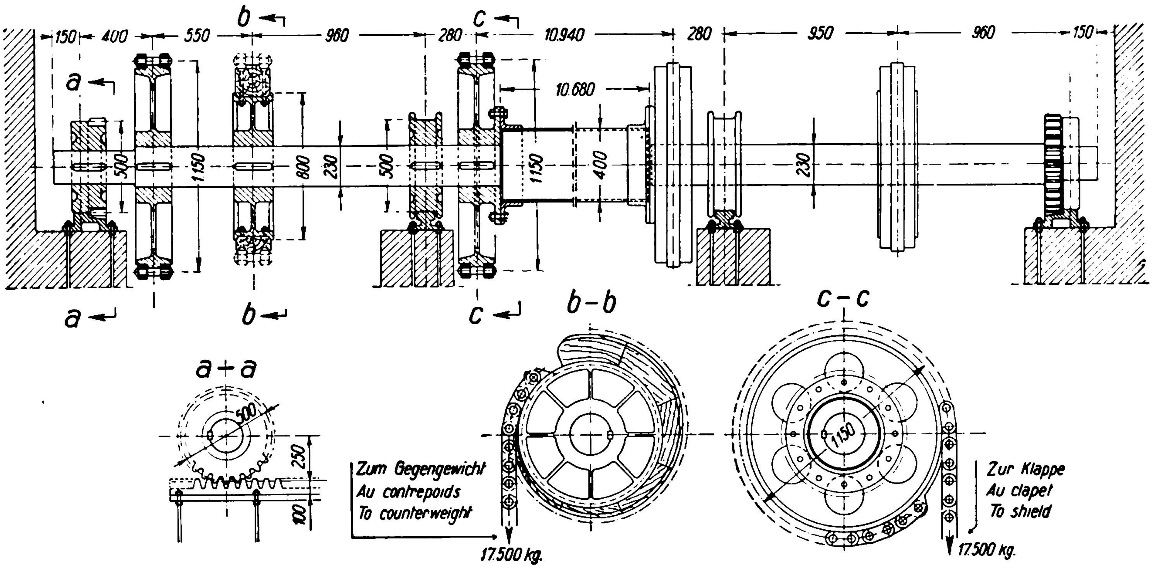

Fig. 10.
Upper bearing and counterweights of overflow trap.

They, as well as the air in the counterweight shafts, are electrically heated when the outside temperature is low, so that the danger of the closures and counterweights freezing up is obviated.

The traps are suspended at the sides by means of chain drums connected together by a steel axle high enough to clear the movable action of the trap; these drums roll on horizontal rails when the trap moves, as shown in Figs. 1 and 10. The cam-wheels regulating the action of the counterweights are mounted on the same axle. These cam-wheels are so calculated that the counterweights maintain equilibrium with the water pressure and the dead weight of the trap in any position of the latter so long as the surface of the water is at the normal level of 380.24. If the water level rises, the pressure on the trap increases and the latter is depressed; on the surface of the water sinking below the normal level, the trap is raised again by the action of the counterweights. The latter were designed somewhat heavier than was calculated, an auxiliary hydraulic force being utilised by connecting the counterweight shafts by means of tubes; the shafts now act as intercommunicating containers, so that by altering the quantity of water in them various degrees of upthrust can be imparted to the counterweights themselves. When the surface of the water rises an overflow feeds water to the shafts, increasing the upthrust on the counterweights, neutralising the overweight of the latter and allowing the trap to be depressed. This movement is again checked when the counterweights emerge from the water contained in the shafts, i. e. unless the surface of the water upstream continues to rise and further overflow is fed to the shafts. Vice versa, the trap cannot return to its erect position before the water in the shafts has been drained off by small overflows. Thus the trap moves smoothly and without the slightest jerkiness.

The two counterweights of each trap are so dimensioned that when they are submerged to a depth of 50 cm the traps are fully depressed, the overflow now feeding a quantity of water to the shafts corresponding to a clear overflow height of 2 cm.

The traps can also be depressed by outside agency, a valve situated below the sill of the trap allowing water to be fed to the counterweight shafts; the action of this artificial raising of the water level in the shafts is the same as if the water had entered normally through the overflow. Furthermore, the traps cope with sudden exigencies, as when a turbine is shut off and the flow of water downstream would otherwise become liable to sudden interruption. The automatic action of the traps not being quick enough in this case, especially if the level of the water is some what low vertically adjustable overflow funnels are arranged in the shafts to permit of the traps being depressed within two minutes of the inlet valve being opened. Thus 40 m^3/sec. of water can be allowed to escape.

Summary.

The paper describes a modern barrage in the damm shutting of the flow of the river contains four doubly-sealed bottom or scouring sluices, the upstream closure having the form of a sliding sluice gate, the downstream closure that of a regulating segmental sluice. The fine regulation of the surface is effected by automatic traps placed on the upper sill of the barrage; these can regulate the surface of the water to an extent of $+$ 2 cm and at the same time cope with sudden exigencies, such as when a turbine is shut off and additional quantities of water have to be let through. The bearings of the sluice gates and particularly their closures and hydraulic or electro-mechancial motive power are of improved design and action, so that the total leakage of the whole barrage is no more than 50 l/sec.