these transformations extend over a large interval of temperature, the liberation of heat does not appear to represent the sum of the points Ar3 and Ar2 corresponding to the quantity of iron present. As the point Ar2 is characteristic of the magnetic transformation it may be supposed either that the point Ar3 disappears above 29 per cent. of nickel, or that it is masked by other superposed endothermic phenomena. They certainly present difficult problems for solution.

MICROSTRUCTURE.

The alloys of iron and nickel may be divided into three groups:—

(1) From A to G (7·65 per cent. of nickel) inclusive, the structure resembles that of ordinary steels without nickel. But the grains of ferrite are, other conditions being equal, of smaller dimensions, and have less tendency to become larger under the influence of high temperatures, thus giving a fibrous appearance to a fracture.

(2) The second group, comprising J, K, and L, extends up to steels with about 25 per cent. of nickel. The usual methods of etching show a structure of straight parallel fibrous bundles in three principal directions (crystallographically they may be of the octahedral form, Fig. 1, Plate 6, 600 diameters magnification). The carbon, at least when in small quantities, is not in the form of segregated carbide. The characteristics are similar to those of martensite, a constituent of hardened carbon-steels. This similarity is more remarkable since the steels of this group are relatively self-hardening.

(3) The third group includes the alloys non-magnetic at ordinary temperatures, and all alloys richer in nickel up to 98·5 per cent. of nickel.¹ The usual methods of etching ordinary steels do not give good results. It is best to employ hydrochloric acid or ammonium chloride, the metal being connected to the positive pole of a bichromate cell. The structure is purely crystalline, Figs. 2, 3, and 4, Plate 6. The crystals become larger and more clearly marked after annealing from a high temperature, Fig. 2, magnification 25 diameters. They may be octahedrons, but as they mutually arrest each other in their

¹ With the same percentage of nickel (24·80) an alloy of 0·16 per cent. of carbon is magnetic, an alloy of 0·65 per cent. of carbon is non-magnetic at ordinary temperatures, after cooling under the same conditions. As regards structure, the first of these alloys belongs to the second group, the second alloy to the third.

growth, the determination cannot be certain. Whatever be the crystallographic system to which they belong, the prepared specimens are very characteristic, Figs. 3 and 4, magnification 600 diameters, and suggest the structure of pure iron above the point A 3, as shown by Mr. Saniter by means of fused calcium chloride.¹ The alloys of this group are usually riddled with small holes after etching, the cause being unknown to the Author.

All nickel steels possess another interesting property, that of easily becoming schistous by forging. The Author has already noted similar facts for ordinary steels, but these not being homogeneous, the elements of the structure, of unequal hardness, are unequally drawn by working. In nickel-steels the laminar structure is superposed on the structures already described. In the metals of the second and third groups it is completely independent, cutting the forms of the crystals. It is shown in all methods of etching by the formation of bands alternately more or less attacked, which allow the deformations due to the forging or rolling to be seen, Fig. 4. When the alloys of the second group are tempered after heating to dull red below the critical point Ac 3-2, the forms of the martensite become less distinct, exactly as with tempered carbon steel.

MAGNETIC PROPERTIES.

Some years ago, the Author suggested ² that the total magnetism up to saturation of any steel might be a measure of the quantity of α iron contained in that steel, and that the residual magnetism, other things being equal, might be a fraction of the total magnetism, which would be greater the smaller the proportion of α iron. It follows that if the hardening carbon, the manganese or the nickel alloyed with the iron increased continuously, the total magnetism should decrease from its maximum to zero, while the remanent magnetism should increase from zero to its maximum, and then decrease to zero.

The Hadfield series of nickel steels was admirably adapted for a verification of these ideas.

The total magnetism was determined by observing the tractive force. Each of the bars, after reheating to cherry-red, followed by cooling on a brick, was placed against one of the poles of a

¹ Journal of the Iron and Steel Institute, 1898, part 1, p. 206, Plates xxii. to xxv.

² Philosophical Magazine, June, 1890, p. 511.

horse-shoe electro-magnet traversed by a current of 5·7 amperes, and the weight necessary for separation was observed. The

TABLE V.

Specimens.		Dimensions of Bars.		Magnetism.	
—	Percentage of Nickel.	Weight.	Length.	Total.	Remanent.
				Tractive Force.	Deviation.
		Grams.	Millimetres.	Kilograms.	Millimetres.
A	0·27	10·285	38·0	4·550	14·7
C	0·94	11·230	38·3	5·050	14·9
E	3·82	9·795	37·6	4·675	25·0
G	7·65	10·770	37·7	3·725	60·0
J	15·48	10·670	36·7	2·725	135·6
K	19·64	11·285	38·5	1·950	124·5
L	24·51	12·345	37·6	0·450	112·3
M	29·07	11·115	36·5	0·050	2·5
N	49·65	12·220	37·5	3·225	4·9

Fig. 4.

TOTAL AND REMANENT MAGNETISM.

method is rough, but is sufficient to follow the general nature of the variation.

To measure the residual magnetism, the apparatus above described for the appearance and disappearance of magnetism was

used. Each bar, after being placed on the pole of the electro-magnet and magnetised by six successive passages of the current of 5·7 amperes, was placed at a fixed distance from the magnetic needle, and the deviation on the tangent scale was observed. The figures obtained are not absolute, but they can be compared one with the other. Care was taken that the bars were magnetised almost to saturation. The results are shown in Table V, and in the curves, *Fig. 4*.

For irreversible steels, the total magnetism is gradually lowered and becomes nearly zero as the percentage of nickel increases from zero to 29 per cent. At the same time the remanent magnetism begins from a relative minimum, attains a maximum in the alloy J (15·48 per cent. of nickel), then slowly diminishes, and evidently becomes zero in the non-magnetic alloys.

These facts agree with the suggested theory. If the relative minimum of the alloy A has a value appreciably great, it is because the alloy contains 0·27 per cent. of nickel, 0·19 per cent. of carbon, and 0·79 per cent. of manganese (quantities which are far from being negligible), and that the cooling in air of a bar 6 millimetres to 7 millimetres square may produce a slight hardening. From M (29·07 per cent. of nickel) the total magnetism again increases rapidly with the percentage of nickel. In the alloy N (49·65 per cent. of nickel) it is perhaps greater than the calculated magnetism due to a mixture of pure iron and nickel. Hopkinson has already noted the same phenomenon in a nickel iron alloy containing 73 per cent. or 75 per cent. of nickel. In the reversible steels the residual magnetism is so small that, on the scale chosen, the curve sensibly coincides with the axis of abscissae.

The curve of total magnetism, *Fig. 4*, is exactly similar in character to the curve of the critical points of magnetic transformation during cooling, *Fig. 3*. As the mechanical properties of steels bear some relation to their magnetic properties, and the magnetic properties are related to the temperatures of the critical points, the mechanical properties are therefore functions of the temperatures of the critical points. It is to be noticed that the absolute maximum of the residual magnetism in the series of irreversible alloys coincides with the maximum hardness.²

¹ Discussion of Mr. Parshall's Paper, "Magnetic Data of Iron and Steel." Minutes of Proceedings Inst. C.E., vol. cxxvi., p. 71.

² See the quoted Papers by Mr. Guillaume and that by Mr. E. Dumont, "Researches on the Magnetic Properties of Nickel-Steels," *Extrait des Archives des Sciences Physiques et naturelles*, Geneva, 1898, published by Rey et Malavallon.

TEMPERING OF THE SELF-HARDENED ALLOYS.

It is well known that certain nickel-iron alloys, especially those containing about 14 per cent. to 15 per cent. of nickel, after slow or rapid cooling from cherry-red, possess somewhat great hardness. Mr. Werth has found that this hardness, like that of hardened carbon steels, may be diminished at will by tempering to a temperature less than that of the critical point of heating. This property shows that the transformation of the alloys considered remains incomplete during cooling from cherry-red, or in general from a temperature above that of Ac 3-2. This fact is one of great importance, since it allows of the metal being softened to be machined, and of being hardened before using it. It has formed the subject of a patent by the Société de Denain et Anzin.

The measurement of the remanent magnetism of short bars gives a convenient method of studying the influence of the thermal treatment. The Author has made some experiments in this direction on the alloys J (15·48 per cent. of nickel) and K (19·64 per cent. of nickel). These alloys were subjected to a series of successive heatings to temperatures progressively diminishing to 634° C. Hardened by this last treatment, they were then subjected to another series of heatings to temperatures progressively increasing, until the initial condition was again

TABLE VI.

	J (15·48 per cent. Ni).			K (19·64 per cent. Ni).		
	Remanent Magnetism.			Remanent Magnetism.		
	Before Mag- netization.	Immediately after Mag- netization.	15 minutes after Mag- netization.	Before Mag- netization.	Immediately after Mag- netization.	15 minutes after Mag- netization.
	Millimetres.	Millimetres.	Millimetres.	Millimetres.	Millimetres.	Millimetres.
Heated to 837	Trace	132·0	118·5	Trace	121·0	106·0
„ 770	Trace	141·0	126·5	Trace	126·6	114·5
„ 710	Trace	146·0	127·9	Trace	131·5	118·4
„ 634	Trace	153·4	141·5	Trace	166·0	150·6
Remagnetized	..	155·9	..	..	169·0	..
Heated to 105	121·0	154·8	152·0	139·6	168·0	163·7
„ 214	?	139·3	138·9	116·5	150·9	150·0
„ 303	76·5	123·7	123·3	93·0	132·3	132·5
„ 370	57·8	98·1	98·0	70·7	104·9	104·9
„ 415	38·0	78·0	78·0	46·4	82·9	82·9
„ 475	25·9	64·0	64·0	30·0	72·1	72·1
„ 514	20·0	64·8	64·5	27·0	78·4	78·0
„ 565	6·8	149·0	136·0	1·0	181·0	171·0
„ 603	Trace	164·0	149·8	Trace	175·0	165·5

reached and the cycle closed. The heating took place in the apparatus used in the researches on the temperature of magnetic transformation. When the desired temperature was obtained, the gas was extinguished and replaced by a current of cold air until the temperature fell to 60° . The bars were then removed from the furnace and allowed to cool for ten minutes. The residual magnetism was measured, the bars were again magnetised by the electro-magnet traversed by a current of 5.7 amperes, and the remanent magnetism was measured immediately, and again at the end of fifteen minutes. The measurements were made, as

Fig. 5.

TEMPERING OF THE SELF-HARDENED ALLOYS.

in the other experiments, in arbitrary units. The results are shown in Table VI and in the curves, Fig. 5. A glance at these curves shows the effect of the successive heatings, the softening and the hardening being clearly shown. It should be added that the results might be considerably modified by varying the speed of cooling and heating. Lastly, it should be remembered that the magnetism is much more stable in tempered than in annealed bars. The above experiments clearly show that in ordinary working these nickel-steel alloys must be very carefully handled.

The Paper is accompanied by two drawings and four photographs, from which Plates 5 and 6 and the Figures in the text have been prepared.

(Paper No. 3060.)

“Sluices of the Betwa Canal-Head and Weir.”

By ROBERT MACALISTER, M. Inst. C.E.

THE calculated flood-discharge of the River Betwa, in India, is 750,000 cubic feet per second. The weir across the river at Paricha, near Jhansi, is 4,000 feet long with a maximum height of 60 feet, and has four sluices 12 feet by 6 feet, with a floor at R.L. 608. Each of the openings is provided with an iron gate on the up-stream, and a drop-gate on the down-stream side (*Figs. 1*). The object of the latter is to close the opening in the event of the iron gate or gear being deranged. The iron gate is 12 feet 3 inches by 6 feet 9 inches by $8\frac{3}{4}$ inches. It has a framework of channel-bars, 8 inches by 3 inches by $\frac{3}{8}$ inch, the horizontal beams being arranged so that there may be equal pressure on each. The vertical channels at the sides extend 1 foot 6 inches above the top of the gate to provide an attachment for the lifting gear. The gate is covered in front with $\frac{3}{8}$ -inch plates, and on the back has two vertical plates 12 inches by $\frac{3}{8}$ inch. The horizontal beams are designed for pressure due to a head of $31\frac{1}{2}$ feet.

Manual labour is the power employed for lifting. Two box girders at R.L. 648 rest on cast-iron bed-plates, bolted down to the masonry to resist the upward thrust in closing the gate. On these girders is secured a cast-iron thrust-block, which is fitted with a gun-metal nut, having thrust collars on the outside. To this nut the capstan head is fixed. The screw, which is of wrought iron $4\frac{3}{4}$ inches diameter, has a square thread, and is provided with a flat end for attachment to the cross-beam below. The ends of this cross-beam are attached to the upper ends of two angle-bar pillars within the grooves. The lower ends of these pillars are attached to the projecting channel-irons on the sides of the gates. The pillars are strengthened by diagonal bracing. The gearing is designed for a pressure due to a $21\frac{1}{2}$ -foot mean depth of water.

The drop-gate is of sāl, one of the heaviest and strongest timbers procurable. It is built up of a series of 8-inch square balks laid over one another and bolted together by four $1\frac{1}{2}$ -inch bolts between

two angle-bars 8 inches by 3 inches by $\frac{3}{8}$ inch on the top and bottom. The bearing-surfaces of the gate have angle-bars 8 inches by 3 inches by $\frac{3}{8}$ inch, and on the bottom a wearing-block of timber is attached which can be renewed without disturbing the fixed portion of the gate. The gate is ordinarily suspended from the drop clip at R.L. 635. After being dropped it may be necessary to raise it under a $31\frac{1}{2}$ -foot head, and for this purpose a 25-ton travelling crab is provided. The crab has a grappling beam attached, on the under side of which are two projecting forks

Figs. 1.

Scale, $\frac{1}{10}$ inch = 1 foot.

GATES FOR WEIR SLUICES.

fitted with pawls, which, on the beam being lowered, allow the forks to pass two Λ -shaped bars attached to the top of the gate, and on the beam being reversed the gate is raised. The chains are wound on two grooved barrels, and the crab is free to travel longitudinally to either side to accommodate itself to the position of the chains on the barrel. Cast-iron grooves are built into the masonry and are bolted together in pairs. The bearing-surfaces of these are planed.

The canal-head has five bays, each having two openings of

6 feet by 6 feet for the regulating sluices on the up-stream side, and one opening 10 feet by 6 feet for a wooden drop-gate on the down-stream side. The bottom of the lower opening is at R.L. 610, and that of the upper opening at R.L. 627. The reason for having a set of gates at a higher level is that, during the rainy season, a small supply of water only is required for the irrigation of the rice crops; and this can be more easily taken off under a less head through the upper sluices at this season, when there is a full supply in the river.

Figs. 2.

GATES FOR REGULATING SLUICES.

The sluices, *Figs. 2*, are of the same general construction, and are similarly worked by screws. The upper and lower gates are of exactly the same dimensions, so that they may be interchangeable. The lower gate is in front of the upper one, and they are worked by independent screws of the same dimensions as those for the weir sluices. The two gates are never worked simultaneously. The bracing of the frame of the lower gate is stopped short in front of the upper gate to provide a clear opening.

The drop-gate, *Figs. 2*, is of the same construction as that for the weir. A less powerful crab is provided, as it is not necessary to raise this gate under such high pressure. The gate is ordinarily suspended from a drop clip at R.L. 642. In the event of the fall being interrupted, provision is made by leaving a slot in the piers to open communication between the bays, to allow of another gate being traversed to this bay, and dropped on the top of the first to ram it down.

The whole of the work was designed by and constructed under the supervision of the Author at the Canal Foundry and Workshops, Public Works Department, Roorkee.

The Paper is accompanied by four photo-prints, from which the Figures in the text have been prepared.

(Paper 3062.)

Irrigation Works in the Jeypore State, Rajputana, India.

By CHARLES EGREMONT STOTHERD, Assoc. M. Inst. C.E.

THE Paper gives a short description of some of the principal irrigation works carried out in the Jeypore State during the last twenty years, showing the different methods which were adopted, and the results attained. The works were all carried out under the superintendence of Colonel S. S. Jacob, C.I.E., Assoc. Inst. C.E., whose services were lent to the Jeypore State by the Imperial Government in 1867, and who has been engaged there since that time.

It is not suggested that the design of the works is the most economical that could have been adopted in each particular case, as in many instances a large margin of safety has purposely been provided, the works being all carried out under the supervision of a single officer, whose multifarious duties precluded the possibility of his constant residence on the work. The methods adopted were also in some cases tentative, but up to the present all have met with a successful result. All the works were constructed entirely by local native agency.

The Jeypore State covers an area of 14,527 square miles, and lies between 25° 43' and 28° 23' north latitude, and 74° 50' and 77° 18' east longitude. The general character of the country is level and open; but there are numerous hilly tracts and ridges with isolated peaks rising several hundred feet above the surrounding plain, constituting a continuation of the Aravali range of hills. They are composed chiefly of quartzite rocks, probably belonging to a period anterior to the old red sandstone of Great Britain, but as they contain no fossils, their exact age is doubtful. In the north these hills contain valuable mines of copper, iron, and cobalt, but for lack of transport and fuel these are not worked at the present day. In the west of the State is the Sambher Salt Lake, where excellent salt is manufactured by the Imperial Revenue Department. A good variety of red sandstone is quarried

in the east of the State, also valuable red and white marbles, while at the town of Bhankri slabs of mica-schist up to 30 feet in length are readily procurable for roofing purposes.

The nature of the soil in the plains varies from black cotton soil in the south and south-west to the sands of Sheikhawati on the borders of the Bickaneer desert in the north. The centre of the State is an elevated table-land, about 1,400 feet above the sea-level, and falling rapidly towards the east and south, where it is only some 700 feet high.

The average yearly rainfall of the country varies from 35 inches in the extreme south to about 20 inches in the north. The whole of this quantity, with the exception of about 2 inches, falls between the middle of June and the middle of September. The yearly rainfall, however, is extremely variable. Thus, at Jeypore City, during 1892, 55·27 inches of rain fell, while in 1877 the fall was only 9 inches; and in the present year 14·10 inches has been recorded—the average for the whole period being 25·78 inches. In the north, on the borders of the Bickaneer desert, the rainfall is still more precarious.

There are several large rivers and streams in the State, but these, with the exception of the Banas, which drains an area of some 14,000 square miles, are mostly dry, except during the monsoon months—June to September.

It is, therefore, of the highest importance to impound, during the monsoon, all the water that can possibly be stored, in order to utilise it for irrigation purposes during the ensuing months, also to provide against the droughts which appear to recur in periods, every fifth, ninth, or nineteenth year, by storing the surplus water of a good year and utilising it in a bad one.

MORAN LAKE.

This reservoir is an instance of an earthen dam in which a core-wall of masonry has been subsequently inserted. It was commenced in 1877 and completed in 1878, and was carried out under the superintendence of the late Mr. T. W. Miles, M. Inst. C.E., who at that time was associated with Colonel Jacob in the Public Works Department of the Jeypore State. It is formed by closing up two gaps in a rocky chain of hills with dams, at first consisting solely of earth. The dams are 3,380 feet in total length, the inner slope being 3 to 1 and reveted with stone, the outer slope 2 to 1, and the top width 20 feet. The drainage area is about 35 square miles, consisting of bare rocky hills; consequently a good per-

centage of the rainfall is secured. When full, the area of the lake is 2 square miles, the greatest depth of water being 28 feet, and the capacity 456 million cubic feet. The total expenditure on the work up to December 1895 was Rs.1,60,365, and up to date it has yielded an estimated average revenue in water rate and share of produce of Rs.24,005 per annum, or 14·96 per cent. per annum. The canals and distributaries aggregate about 56 miles in length.

On 25th July, 1882, a heavy fall of rain occurred, and water flowed over the three waste weirs, 421 feet in total length, to a maximum depth of 2 feet, from 6 A.M. to midnight.

The Babul trees planted on the slopes of the embankment were afterwards cut away and their roots removed, as they were found to be dangerous in the rainy season; the movement of the trees by the wind having a tendency to loosen the soil and to allow water to creep along the roots. The reservoir constantly overflows, and it is only on account of the submersion of property which would occur that has prevented its being raised 2 or 3 feet. In 1886 a masonry core-wall was inserted into the bank where it crosses the bed of the stream, a length of 605 feet, and in 1892 a further length of 900 feet of masonry core-wall was built. The reason why masonry core-walls are not always adopted is, that it is advisable to keep the original cost of these works as low as possible. In many cases experience has proved that masonry core-walls are not necessary—where there is any doubt, and no fear of the consequences of a breach, they have been omitted, and added when the necessity has arisen.

With black cotton soil, or soil composed of earth mixed with kunkur nodules, the core-walls are almost indispensable, as these soils gutter very badly, and, though as hard as rock in the dry season, become very soft during the rains. Failure in embankments consisting solely of this earth frequently results from the holes which animals make during the dry season. An instance is recorded of a leak through one of these holes gradually enlarging till a tunnel 10 or 12 feet high was formed in the embankment, which remained standing after the whole of the water had escaped from the reservoir. It is the practice, therefore, to have such holes carefully stopped each year before the commencement of the rains.

The average cost of the uncoursed rubble masonry, such as is built in these core-walls, is from 10 to 15 rupees per hundred cubic feet, the rate varying of course with the proximity of the materials.

KALEGH RESERVOIR.

This reservoir has an embankment composed entirely of sand, but abutting on to rock at one end. It was commenced in 1880 and completed on 11th October, 1882, and is, financially speaking, the most paying irrigation work in the State, having cost up to December 1895 only Rs.2,59,087, while the revenue realised averages Rs.40,788 annually, a return of 15·75 per cent. per annum. The capital cost of the work was paid off within eight years of the date of its completion.

The project consists of impounding the waters of the River Bandi at a point where its course passes between the rocky spur of Kalegh Hill and some sand hills to the north. The river at this point was 305 feet wide. The embankment is composed entirely of sand, the inner slope is 4 to 1, and the outer slope 3 to 1, the width at the top being 20 feet. At the point at which the embankment abuts on to the rock a core-wall of masonry, 30 feet long and 2 feet thick, was built into the dam to prevent water creeping along the face of the rock and endangering the sand dam. Rubble at the toe of the outer slope 10 feet wide and 3 feet high prevents any erosion of the outer slope. These measures have been completely successful. The length of the dam is 730 feet at the top and 305 feet at the bottom, and the height 50 feet. The greatest depth of water impounded is 30 feet, of which 25 feet is available for irrigation, the remaining 5 feet being allowed for any silting up which may subsequently take place.

The drainage area above the bank is 227 square miles, and consists of a level sandy plain, except at the source of the river, which is in rocky hills. One feature of the work is the waste weir, which is cut out of the rocky spur of Kalegh Hill, and is only 100 feet long. This has been found more than sufficient for all contingencies, because the area of the lake at the 30-foot contour is no less than 1,540 acres, and the very sandy nature of the catchment area prevents much run-off at any time.

The total capacity of the tank is 578 $\frac{3}{4}$ million cubic feet. Two cast-iron outlet sluices, each 3 feet diameter, are provided in the centre of the waste weir.

A well is provided in front of these outlet sluices, in which a 3-foot sluice is placed. This is kept open, but can be closed to enable the other two outlet sluices to be inspected in case of necessity. Subsequent experience shows that sluices of 2 feet diameter are sufficiently large for all purposes. The stone

excavated from the spur to form the overflow weir was spread over the inner face of the dam to prevent any scour of this face.

The canal starts about 6 miles below the dam, where a masonry weir, 12 feet high, founded on rock, has been built across the course of the Bandi, to raise the level of the water to the irrigation canal. The water from the reservoir, controlled by the sluices, runs down the course of the river, and is diverted by the weir into the canals and distributaries as it is required. Owing to the hilly or broken character of the ground no irrigation is possible on either bank of the river for the first 7 or 8 miles. The sluices to supply the canal consist of five openings, each 4 feet square, founded on rock. Scouring sluices are also provided in the weir to keep the head works free from silt. The canals consist of 55 miles of main canal, and 118 miles of distributaries.

The first year's rainfall impounded was that of 1881, before the completion of the work, when the reservoir filled to within 2 feet of the waste weir level. The rainfall of this year, June to September, was 18 inches. In 1882 only 13 inches fell during this period, but the reservoir again filled to the same height. In 1883 the reservoir filled $23\frac{1}{2}$ feet, *i.e.*, to $6\frac{1}{2}$ feet below waste weir level, with a rainfall of 20 inches. In 1884 the reservoir filled for the first time, 6 inches of water also passed over the waste weir, the rainfall for the year being 21.79 inches. In 1885 discharge over the waste weir from 21st August to 25th September occurred to a maximum depth of 2 feet 1 inch. In 1886 the water level in the reservoir was raised 1 foot by building a small masonry wall on the overflow weir. By this means its capacity was increased by 74 million cubic feet. In 1887 the depth of water over the waste weir reached 2 feet 3 inches, the greatest depth recorded to date.

TORI RESERVOIR.

This is the largest reservoir in the Jeypore State, covering when full an area of 6.35 square miles. With the exception of the Jai Samand in Udepur territory, it is also the largest artificial lake at present existing in Rajputana. A river, known as the Sohadra, which has its source in the Ajmere district, passes over a rocky bed at the site of the dam near the village of Tori, south of the hill of that name. Exclusive of areas cut off by smaller irrigation schemes, the area of catchment above the site of the dam is about 320 square miles. It is hilly at the sources of the river, but chiefly consists of a wide cotton soil plain.

The average rainfall for the district, calculated over 14 years, is 21·84 inches.

The length of the bank is 6,400 feet, the greatest depth of water 40 feet, and total capacity of the tank 1,750 million cubic feet, capable of irrigating 43,750 Jeypore Bighas, or 14,583 acres. With the exception of 1,500 feet at the north end of the dam, a core-wall has been built in the bank which forms, above the high-water line, a retaining wall for the earth (*Fig. 1*).

A level berm, 10 feet wide, is made at high-water level to prevent the earth being cut away and the core-wall exposed. The inner slope of the dam is 4 to 1, the outer $2\frac{1}{2}$ to 1. The inner slope is protected by a layer of kunkur and stone, 1 foot thick, to prevent waste guttering the slope.

The waste weir is 1,000 feet long, of which 700 feet is built up, the remainder being on the natural surface of the ground; it is situated at the south end of the dam. The disadvantage of

CROSS-SECTION OF THE TORI DAM.

making the waste weir at one end of a dam is that any overflow has to cross the irrigation canal on its way back to the river. If the overflow is great, as in this case, it may cause damage to the canal and necessitate protective works—to pass off the surplus water—either under or above the canal. The masonry core-wall is founded on rock when possible, and where no rock existed the foundations were carried down 8 feet below the surface of the ground to a substratum of sound earth, and the wall built on a bed of concrete, well consolidated. The outlet channel to the sluices has been cut in solid rock to points in the dam well above the original course of the river; the object being to secure a site where the height of the bank is small, and the foundations good, also to enable the canals to be conveniently led away. This course is always adopted to diminish the risk of the failure of the dam at the sluices, through water creeping along between the masonry and earthwork, or beneath the foundations.

There are two main canals, $47\frac{1}{2}$ miles long, led away from the
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dam north and south of the course of the river, the breadth at formation decreasing from 20 feet to 12 feet, and side slopes 1 to 1. The irrigation ducts at present aggregate 67·32 miles. Where cross drainage meets the canals core-walls or waste weirs have been built, so as to dam them up and divert their waters through the canals into adjacent reservoirs, or, if the volume of water is very great, to allow its free passage over the canal.

The total expenditure up to 31st December 1895 has been Rs.5,77,753; the average annual revenue now collected being Rs.48,299, giving an average return of 8·36 per cent. on the total cost of the work.

The water from the outlet sluices before reaching the canals passes through a turbine, which is used for grinding corn.

The work was commenced in May 1882 and completed October 1885. In 1883 the work was proceeded with, a gap being left at the river to provide for the escape of its flood waters.

In the construction of the work, Decauville's portable railway 16-inch gauge was used, with great advantage, for the earthwork and transport of material.

In addition to the ordinary sluice valves, grooves have been provided in the cut stonework of the wells in front of each set of sluices, into which planks can be fitted to permit access to the valves should they ever get out of order. In 1885 the first year's rainfall was impounded; a fall of 6·5 inches on the 25th of August filled the reservoir to within 3 feet of waste-weir level. In 1887 the reservoir filled, and for about 40 days 11 inches of water ran over the waste weir. The monsoon rainfall over the catchment area in this year was 32·50 inches. In 1888 there was a very heavy fall of rain, amounting to 8·45 inches in 9 hours; the maximum depth of water over the waste weir was 2 feet, and the overflow continued for 29 days. The total monsoon rainfall of the year was 26·74 inches. In 1889, with a rainfall of 25·77 inches, the reservoir again filled. In 1890 the reservoir filled to the 34-foot contour, or 6 feet below waste-weir level, while in 1891, the year of famine in West Rajputana, only 6·04 inches of rain fell on the catchment area, and the reservoir again remained unfilled; but in 1892 38·36 inches of rain fell in the monsoon, and the reservoir filled to overflowing. In 1896, a year of almost universal famine in India, the reservoir filled to within 6 feet of the waste-weir level, and the water was the salvation of the surrounding districts. It would thus appear that to provide for an average rainfall the capacity of the tank has been very correctly estimated. The result of 14 years' observations gives 21·82 inches

as the average annual rainfall of the district, and the capacity of the reservoir being 1,758 million cubic feet, it would appear that on the average only 2.25 inches of the whole rainfall runs off, that is, about 10 per cent. The high-water level was fixed at 40 feet, and could not be raised without submerging the village of Miron, which was not advisable. It is an interesting fact that since this work was finished no less than 35 new hamlets have been established in the land irrigated by the lake, where formerly nothing but jungle existed.

BOOCHARA RESERVOIR.

In the hills near Boochara, about 55 miles north of Jeypore, the waters of the Sota River have been impounded by a masonry dam

Fig. 2.

CROSS-SECTION OF THE BOOCHARA DAM.

80 feet in height at a point where it emerges from a hilly tract about 80 square miles in area. The length of the dam is 480 feet at the top and 130 feet at the bottom, and was purposely made somewhat thicker at the base than was theoretically necessary (*Fig. 2*). The area of the reservoir is 1.75 square mile at top-water level, the greatest depth being 75 feet, and the total capacity 1,328 million cubic feet. Two low places in the circumference have been closed by earthen banks, and two or three other places by masonry dams. The outlet sluices are situated at a different point, a channel being cut through the rock from the reservoir to them. They are in duplicate, one set in the outer, the other in the inner wall. In front of the sluices a masonry wall with two grooves has been provided, in which planks can

be inserted in order to examine or repair the sluice valves. There are three waste weirs, two to the south and one to the north of the main dam, having an aggregate length of 746 feet. The length of the main and irrigation canals is 73·75 miles.

The total expenditure up to 31st December, 1895, has been Rs.3,20,487, and the average annual revenue realised Rs.19,155, or 5·98 per cent. on the total cost of the work.

The part of the country in which the lake is situated was formerly notorious as the resort of dacoits.

The work was commenced in March 1884. A solid rock foundation at the site of the dam was obtained, 15 feet below the bed of the river, but the work on the foundations was seriously delayed in June by floods, and after the rains ceased malarious fever and dysentery attacked the workpeople. It was noted as a remarkable fact that those who were encamped on that side of the river which was exposed to the prevailing south-west winds sweeping over the basin of the proposed lake, suffered very badly from fever, while the windward side of the river remained comparatively healthy. The same phenomenon has been observed at Jeypore in the case of the Amanisha River at the waterworks reservoir, the healthy side being the windward side of the river.

In the following year, 1885, the fever was again so prevalent that nearly 6 working months of the year were lost.

About 1,600 men were employed on the work, and over 400 bullocks, donkeys, camels, &c., for transport of material. During this year the dam was carried up to a height of 40 feet, and all surplus water coming into the reservoir during the rains flowed over the uncompleted dam. The work was directly in charge of a native assistant-engineer and two sub-overseers.

Some difficulty was experienced in getting the main canal away from the hills surrounding the reservoir. After passing through heavy rock cutting the canal crossed two large rivers; one of these was impounded by an earthen bank, the other was crossed by a masonry aqueduct.

On the 15th October, 1886, the dam was completed. The rainfall was short this year, and only 55 feet of water came into the reservoir. In 1887 the reservoir filled, and water, to a depth of 9 inches, flowed over the waste weir for 5 days. This was equivalent to a run-off of 23 per cent. of the rainfall. In 1888 only 16·85 inches of rain fell, and 5 feet of water came into the reservoir, raising its level to the 58-foot contour. This was equivalent to a run-off of 4 per cent. only of the rainfall. In 1889 the water rose 21 feet in the reservoir over and above the previous

year's balance; this is 18 per cent. of the rainfall. 1890 and 1891 were bad years of rain, only 13·14 and 9·3 inches falling. 1892 was a good year, 24·65 inches of rain fell, of which 23 per cent. ran off.

SUMMARY OF RESULTS.

Name of Work.	Drainage Area in Square Miles.	Nature of Catchment.	Average Rainfall over Catchment.	Capacity of Reservoir.	Percentage of Rainfall provided for in Reservoir.	Amount of Water stored per Rs.10 = £1, calculated on the Cost of the Dam, Waste Weir and Sluices only.	Amount of Water stored per Rs.10 = £1, calculated on the Cost of the Dam, Waste Weir and Sluices, including all Costs, Canals, etc.
	Sq. Miles.		Ins.	Million Cub. Ft.		Cubic Feet.	Cubic Feet.
Moran Sagar ¹	35	{ Surrounded by hills }	28	456·50	20·00	60,800	33,010
Kalegh Sagar ²	227	{ Sandy and flat }	25	578·75	4·36	48,050	24,930
Tori Sagar ²	320	{ Black cotton soil —flat }	22	1,753	10·68	55,120	34,040
Boochara reservoir ³	80	{ Hard ground and hilly }	21	1,329	34·00	94,810	49,880
Amanisha water-works at Jeypore }	13	{ Very deep sandy soil, except at sources . . . }	26	{ 148 at 46 feet contour }	4	13,890	

In 1893 an extraordinary flood occurred on 11th July, when, although no rain fell at the site of the dam, in 8 hours the water rose from the 58-foot contour, filled the reservoir, and rushed over the waste weirs to a depth of 4 feet. As a careful record was kept of the duration of this flood, it is calculated that the actual discharge was about 15,854 cubic feet per second, as against 22,068 cubic feet per second, calculated by Colonel Dicken's formula for a drainage area of 80 square miles, and a total run-off for that day of 1,813 million cubic feet of water, or more than sufficient to fill

¹ Probably 25 per cent. might have been provided, as this tank frequently overflows.

² This percentage is about correct for average rainfalls.

³ Double the usual rainfall provided for to guard against the frequent water famines; 23 per cent. has been observed as the actual run-off from an average year's rainfall.

⁴ Reservoir has never filled beyond the 31½-foot contour; 2 to 3 per cent. is the run-off.

the reservoir. 1894, 1895, and 1896 were not years of good rainfall. It is thus apparent that for years of normal rainfall of 25 inches, a run-off of about 20 per cent. may be expected from this hilly track, while in bad years it is as little as 4 per cent.

As the rainy season advances or is prolonged, so the ratio of run-off to rainfall increases, and no fixed percentage can be stated.

GENERAL.

From these results it appears that with a rainfall of 20 to 25 inches per annum a run-off of 25 per cent. should be provided for in case of rocky ground in hilly districts, 10 per cent. in flat black cotton soil country, and 5 per cent. where the catchment is sandy. The larger the rainfall of course the greater the proportion of run-off, as shown by the results of Mr. Binnie's observations at Nagpore.

The total number of completed irrigation works in the Jeypore

Year.	Amount Expended.	Revenue.
1868	227	
1869	23,853	
1870-71	22,772	
1871-72	44,529	
1872-73	68,019	4,337
1873-74	63,590	5,623
1874-75	52,690	15,919
1875-76	70,452	6,443
1876-77	2,26,038	10,649
1877-78	1,52,663	22,590
1878-79	1,25,218	21,900
1879-80	1,20,766	66,589
1880-81	1,28,588	79,962
1881-82	1,42,765	65,205
1882-83	2,38,624	1,39,281
1883, 9 months	1,67,207	1,62,065
1884	3,11,440	1,25,730
1885	4,28,511	1,35,117
1886	2,80,592	2,01,600
1887	2,97,408	1,65,778
1888	1,93,357	3,09,775
1889	1,22,420	2,74,600
1890	1,13,767	3,19,072
1891	96,855	2,43,831
1892	2,18,851	1,91,771
1893	2,55,879	2,67,491
1894	2,56,778	2,47,845
1895	1,53,435	2,55,526
1896	1,40,465	3,23,286
Total Rupees	45,17,759	36,61,985

State is 138, with a storage capacity of 11,141·65 million cubic feet, irrigating 124,002 Jeypore Bighas, which is equivalent to about 41,334 acres.

This does not include the water stored in Zemindars' tanks, which is not available for irrigation, but is used for drinking and ablution purposes only.

It has been found that an allowance of 40,000 cubic feet of water per Jeypore Bigha, or 120,000 cubic feet per acre, is sufficient to provide for all contingencies, including loss by evaporation and absorption. In black cotton soil one watering is often sufficient, while in the lighter soils two are required.

In studying the column of figures in the above Table, it should be remembered that it is frequently cheaper to build the dam a little higher than to cut down the ground to form a waste weir, especially if the site of that weir is in hard rock, as is generally the case, so as to withstand the rush of water over it when the reservoir fills. Increasing the capacity of the reservoir, moreover, has the additional advantage of storing the heavy rainfalls and the surplus of years of heavy rainfall, and thus helps to tide over the dry years, while the additional area of the lake at high-water level reduces the necessary length of waste weir.

On the preceding page is a Table showing the expenditure on these works since 1868, and the revenue realized.

The Paper is accompanied by nine tracings, from a selection of which the Figures in the text have been prepared.