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T. HAWKSLEY, President,
in the Chair.

No. 1,326.—“On the Soonkêsala Canal of the Madras Irrigation and Canal Company.”¹ By JOHN HERBERT LATHAM, M.A., M. Inst. C.E.

THE object of this Paper is to give a general description of the canal between Soonkêsala and Cuddapah, recently constructed for irrigation and navigation by the Madras Irrigation and Canal Company; and also to direct particular attention to the mode of safely constructing high banks for canals or tanks, illustrated by that work.

It seems not to admit of doubt, that the countries possessing the greatest powers of production are those in which the yearly rainfall is concentrated into a few months; as it is certainly beyond doubt that the innate resources of such countries are up to this time the least developed. Settled warm weather is the safest for crops at every stage of their sprouting, growth, and ripening; and, not only in England but in India, it is found that crops grown during uncertain weather, as all unirrigated crops must be, are nearly as often and as severely injured by rains or floods as by drought. Egypt, as far back as history exists, has been a country of settled weather, and also notorious for its fertility; yet that country, even as far as irrigation has gone, can scarcely be called more than half developed. To fully develop the productive powers of land three things are needed: first, settled weather, which art cannot give nor control, and can only turn to account; secondly, irrigation, which must be controlled by art, though a supply must exist upon which art may operate; and, lastly, manure. When it is considered that good land, under constant cultivation in a settled climate, may utilize a ton of guano an acre a-year, besides more bulky and less potent manures, it is impossible not to think what a population the world is capable of supporting, and how unnecessary it is that so many mouths in the most industrious nations are insufficiently filled.

From time immemorial the native inhabitants of the Madras

¹ The discussion upon this Paper occupied portions of two evenings—having been resumed on the 9th of April—but an abstract of the whole is given consecutively.

Presidency have spent large sums in the construction and management of undertakings having for their object the application of water to irrigate fields and gardens. The only native engineering buildings in the country consist of works of irrigation, fortification, religious worship, and shelter for travellers; and of these, in magnitude and importance, works of irrigation rank the first. These have been of three chief kinds, viz.:

I. Wells, which are generally large square pits lined with stone, from which water is raised by simple machinery and delivered on to the fields.

II. Tanks or reservoirs, which are filled by rain-water, and from which the water flows through sluices on to the fields.

III. River channels, of which the canal under review is one. These are the most prized of all the methods, and are stated to give 25 per cent. more crop per acre than either wells or tanks. In some few cases tanks were supplied from river channels, as at Nundloor, Nellore, &c.

River channels were constructed for turning the water of rivers on to the fields in such a way that a nearly constant supply should flow down them, whatever floods should come down the river. Unless so constructed they required to be annually closed, near their entrance or offtake from the river, by a bank; for head sluices were rarely made. The first object, viz., an offtake of constant supply, is accomplished in various ways. If the river-bed be a broad ill-defined one of deep sand, channels are cut parallel to the river along its margin, having their bed lower than the summer level of the water in the sandy river-bed, the spoil being thrown towards the river to make a flood bank, and prevent the river floods flowing into the channel. The up-stream end of this flood bank would abut upon any natural sandhill or other eminence. After running down a mile or two, the channel is given a less fall than the river, and is gradually brought out of the river-bed. Such channels flow by filtration, whether the river be quite dry or in full fresh. They are numerous on the rivers Châyér and Chittrawutty. On the other hand, if the river-bed be rock, a constant offtake may be secured by carrying a rough weir of loose stones across the rocky bed of the river, and returning it downwards under each bank on the margin of the river-bed, until out of the reach of floods; as at Hoosoor, Darojee, &c. The upper side of each return forms the inside of the channel, and is well lined with earth and vegetation. The weir and returns have their crests all at the same level; and the channel runs with a slight fall from the ends of each return.

Where the formation of the ground is such that a channel of the former sort in a sandy river would be carried away yearly, the side channel is abandoned, and the offtake channel requires to be banked across its mouth yearly to prevent the floods running down it and doing damage. This can be conveniently done at the close of the dry season; and when the rains are over and irrigation is needed, the entrance is cleared and a catch bank of sand is constructed in the river-bed to divert the water of the river into the channel. This catch bank is run farther and farther out upward across the stream as the river falls, and at an angle of about 30° with the direction of the stream, so as to keep the supply to the channel constant, until the bank may perhaps extend right across the river. Similarly, where the formation of the ground is such that a weir in a rocky river cannot be returned along the rocky river bank, the channel has been run directly from the end of the weir and at once completely banked off from the river. The case or cases of head sluices being built to such channels before the English rule are so few that it can be hardly called Hindoo practice to build them at all, so far as the Author's personal experience goes. To prevent excessive damage from the river floods, the entrances of such channels are generally cut very narrow, and, if possible, in solid rock; and numerous waste weirs are placed along the channel in the course of the first mile or two in order to get rid of the surplus water poured in by floods through this narrow entrance.

English Engineers soon adopted the rule of placing head sluices across all river channels at or near their entrance. They also extended the use of weirs to sandy rivers as well as to rocky ones, as more effective than the annual bank of sand. Scouring sluices were inserted (not always judiciously) in the weirs, to keep down the silt in the pond above them, and to clear the face of the head sluices of the channels led off from the pond. These scouring sluices are invariably in Madras called "undersluices," whether in the weir or not, though, in the latter case, no water goes over them. Indeed none of the so-called "undersluices" of the Madras Irrigation and Canal Company are strictly undersluices, but they are merely low-level scouring sluices built at the end of the weir, and generally in a line with it.

By great energy some of the engineers of the Madras army induced the Madras Government tentatively to adopt these innovations in situations admirably chosen for the trial; and weirs were constructed at the head of all the considerable deltas—as the Cauvery, Kristna and Godavery—of rivers having a sufficiently

constant flow to irrigate fields for one crop at least of rice each year. The channels from these weirs run along the uniform slope of the delta country, rarely crossing any considerable drainage, and diverge like the rays of a fan from each end of the weir.

The first result of the great success of these innovations was the extended use of similar permanent weirs at the heads of channels, for rivers of very short and uncertain flow, which, instead of running to the fields, run into a series of ordinary village tanks. Of such a kind is the Nellore Anicut across the Pennêr. By its means the floods of the Pennêr are distributed; but, as in London, each householder, so in Nellore, each village, irrigated by the weir, has to provide and keep in repair its own tank to receive and store the intermittent supply, as well as an escape weir for the passage of surplus water to the next tank below. These tanks rarely exceed 1 mile in breadth and 9 feet in depth of water. Other rivers have received, as the Palâr, &c., or deserve, as the Soonamooky, &c., similar treatment.

While the rebuilding of the Nellore Anicut, since it was last carried away, was making progress the "Toombuddra project," for using the inland rivers for irrigation, was adopted by the Secretary of State, so far that interest was guaranteed on £1,000,000 to be raised by the Madras Irrigation and Canal Company, towards carrying out a definite portion of that project for irrigation and navigation combined. The objects of the Toombuddra project, of which the Soonkésala canal is a portion, were two: the first, continuous irrigation throughout the year of three large areas, of which the largest lies in the Bellâry District, the next in the Koondêr Valley, and the other in the Nellore District. The second object, apparently necessary to the success of the first, was a means of communication by canals, by which the produce of these areas could be sent to a market more cheaply than by cart or railway, more expeditiously than by cart and more securely than by railway. In order to maintain irrigation, the autumn and winter supply of the river Toombuddra itself was to be directly distributed to the fields over these areas, and the surplus autumn rainfall was to be stored in large tanks near the sources of the Toonga and Budra in the western hills, in sufficient quantity to maintain the irrigation when the river Toombuddra (Toonga-Budra) itself failed. Navigation could thus be maintained along the line of irrigated country, either in the channel used for the distribution of water or in separate canals. Navigation is particularly suited to India, both on account of its cheapness and security. Two arrangements seem necessary for security, viz., that the goods should not be transferred

from one vehicle to another during the whole journey, especially where other similar goods are being similarly transferred; and that the owner or his agents should be allowed to accompany the goods in whatever vehicle they be placed, and that he should be able to do so in comfort. It is not petty pilfering, but wholesale change of large consignments of grain or cotton, of which the Indian merchants express fears and relate their experience.

This Toombuddra project is one of great importance, not only for India but generally, on account of the hitherto insurmountable difficulties it is intended to meet. These are three in number. In the first place, it proposes, by the mere offer of water, to induce a vast population of ill-educated and poor ryots or cultivators to forsake in great measure the cultivation of dry grain—the only cultivation they know either by experience or tradition—and to undertake a more expensive and intelligent system of agriculture. No doubt, wherever water has already been used from time immemorial, as in the delta countries or in Scinde, it is highly prized; and additional security or extension of the supply is there immediately taken advantage of by the ryots, if the terms suit them. But in the parts of Bellâry, Kurnool, and Cuddapah proposed to be supplied with water by this project, it is not so much the extension, as the introduction of wet cultivation that is aimed at; not the irrigation of dry crops of corn, as on the Ganges and Jumna canals, but the superseding of dry crops by wet, and that without any of the compulsion inseparable from Government works.

A second difficulty is the necessity for the provision of a constant supply of water, by storing it in sufficient quantity for all the work, for use in the dry months. For this purpose it will be necessary to construct tanks or reservoirs, having banks as high as, and longer than, any constructed in historic times, and to provide these reservoirs with surplus weirs or sluices, which on account of the great uncertainty of rain in India, and the great range through which the yearly discharge varies, will need to be of extraordinary discharging power.

The third difficulty lies in the adverse character of the country. Throughout its whole length the Toombuddra valley is crossed by ridges of hills, which render it difficult to carry off channels from the river. Hence the canals executed or projected by the Company have some very heavy cutting and banking before they can be led away from the river so as to command a large area of country. The ridge of hills which crosses the Kristna valley just below the

confluence of the Toombuddra and Kristna, is about 25 miles wide, and its summits are nearly 3,000 feet high. The river passes through this ridge in a narrow and sinuous course, between high and often precipitous banks, for a distance of upwards of 60 miles. Neither navigation nor irrigation could be carried through such an obstruction. Instead of being surmounted, the flank of the ridge is turned by a canal on the level of the watershed dividing the Toombuddra basin from that of the Pennêr, which flows into the sea at Nellore. The canal already completed has its off-take from the Toombuddra, at Soonkêsala, 17 miles above Kurnool, and after a tortuous course of 75 miles, in which it passes over the river Hindry and three other considerable tributaries of the Toombuddra, at an average cost of £8,000 a mile, arrives near Metacondâl, at the watershed between the river Bôanâssey, a tributary of the Kristna, and the Kâli or Caulee, a branch of the Koondêr, a tributary of the independent river Pennêr. There can hardly exist a valley more favourable for irrigation than the Koondêr. The soil is good, the valley broad and flat, and the disposition of the levels, or slope of the ground, excellent. Indeed, when once the Metacondâl watershed is passed, irrigation becomes almost as easy as it is from the weir at the head of a delta country, and the cost of the canal was, for the rest of its course, only £2,900 a mile.

To pass on to a description of the canal itself. (Plate 14.) The Toombuddra project was first brought forward by Colonel Haviland, but it was not till 1858 that the Madras Government, on the report of General Sir Arthur Cotton and other Engineers, selected it as the first work to be undertaken by the Madras Irrigation and Canal Company. In 1861 that Government limited the work of construction under the guarantee to the canal between Soonkêsala and Cuddapah, and the weir at Somêshwaram; and in 1866 made terms with the Company for completing the canal between Kurnool and Cuddapah by the 1st July, 1871.

The character of the canal may be sketched as follows: the first 75 miles is calculated to carry 400,000 cubic yards of water per hour at the head at Soonkêsala, and, after gradually parting with about 100,000 cubic yards for irrigation, to convey at least 300,000 cubic yards an hour through the Metacondâl cutting at its other extremity. There 255,000 cubic yards an hour may be discharged into the Kâli, and 45,000 cubic yards carried down the continuation of the canal. Of the 255,000 cubic yards an hour poured into the Kâli, the canal is calculated to take up 100,000 cubic yards at Jutoor and 50,000 cubic yards at Râjoli, leaving above 100,000

cubic yards of water per hour for the insignificant irrigation below Cuddapah and for Nellore.

The canal begins at Soonkêsala with a weir, Figs. 3 and 4, Plate 15, across the river Toombuddra, 1,500 yards in total length of clear over-fall, which is broken into two lengths by an intervening island. The weir stands upon the rocky river bed, and is formed of three patterns, viz.: 1. Of solid rubble masonry of gneiss, trap and quartzite boulders, of the form Fig. 3. 2. Of gravel concrete, with gneiss rubble facing in front and rear, of the same section. 3. All recent portions are of solid gneiss rubble masonry, with a facing on the lower side of Kurnool limestone ashlar, which averages $\frac{3}{4}$ yard thick where exposed to concussion. Fig. 4. Patterns Nos. 1 and 2 have a front and rear batter of 1 in 8; while No. 3 has an upper batter of 1 in 4, and a rear face vertical. All are 8 feet broad at the top, and coped with dressed limestones 1 foot thick, of which every alternate one is a through stone 8 feet long, weighing about $1\frac{1}{2}$ ton. The mortar throughout is of Kurnool kunkur, except the joints of the coping, which are of Portland cement. The coping is joggled wherever the anicut (which is not straight, but follows the line of highest solid rock) is concave in plan on the up-stream side. No part of the anicut formed on any of the above patterns, either with or without the coping, has ever failed. The height varies from 6 feet to 26 feet, and averages about 18 feet; and the highest registered flood rose $7\frac{1}{2}$ feet over the crest.

From the pond above the Soonkêsala weir the water is admitted into the canal by a head sluice without any lock. The face of the head sluice is kept clear by the scour of ten under-sluices at a lower level in the weir, the stream to which is forced against the front of the head sluices by a long curvilinear groin. The minimum cross section of the canal for the first 75 miles has a 90-foot bottom, with 2 to 1 side slopes. For the first 45 miles the fall per mile is adapted to secure a discharge of 400,000 cubic yards of water an hour, if requisite, without increasing the depth of the water to more than 8 feet. Below the 45th mile, the canal being in good soil, and lying on easy slopes with limestone or shale subsoil, a depth of 9 feet of water is allowed. At the 75th mile the canal passes through the watershed between the Toombuddra and the Pennêr rivers; and thence the natural water-course becomes the main supply channel, under the successive names of the Kâli, the Koondêr, and the Pennêr. From this natural main supply channel the water is taken at four points, viz., Lockinsula, Jutoor, Râjôli, and Adanimayapilly, by the simple process of throwing

weirs across it, with under-sluices in the weirs to keep down the silt, and head sluices across the channel to control the supply and entrance locks.

The first branch irrigating channel forms the main canal from the 75th to the 95th mile. Its head is formed at Lockinsula by blocking up the water-course (there so rudimentary as to have been used for a village road) by a bank with scouring sluices, and turning the main supply over a natural weir of rock, whence it joins the old water-course below. The head sluice and lock are adapted for working this branch with a depth of 6 feet of water, when the irrigation becomes sufficiently extended to require it in the Nundi-cotacoor and Nundial Talooks, and at this depth the flow will be 45,000 cubic yards an hour. This canal is an irrigating channel for the first 6 miles only. Below that it is a still-water canal, with a fall of 180 feet 5 inches, overcome by seven double-chambered locks and five single-chambered locks. The greatest drop in any one double lock is 21 feet 8 inches, and in a single lock 13 feet. The chambers are 120 feet long, by 20 feet broad. The canal is 45 feet wide at the bottom, and the minimum depth is 5 feet.

The second branch irrigating channel takes its supply from the main stream in the Kâli at Jutoor, and forms the main canal from the 95th to the 146th mile. It has a very wide area of distribution in the Nundial, Seriwell, and Koilcoontla Talooks of the Kurnool district. It is intended to distribute 130,000 cubic yards of water an hour, if required; but to do this 2 feet height must be added to the banks over the first 20 miles of its course. In its present form it is adapted for carrying about 100,000 cubic yards an hour; and this is probably enough to supply rice for all the local demand for food, leaving the cultivation of cotton and indigo, for which the valley is celebrated, more room than is available while dry grain has to be grown for food. Already the Company has irrigated a greater area of dry than wet crop in this valley. A good indigo crop is of more value as an article of commerce than a good rice crop, but hitherto indigo cultivation has been so precarious that a really good crop might not be obtained once in six years. No crop more needs and repays irrigation. The head works consist of a weir (Fig. 5) of solid limestone in rubble masonry founded on soft shale, and of head sluices, the face of which are scoured by under-sluices in the weir by help of a training wall and of an entrance lock. The weir is 6 feet broad below the coping, and has a batter on the upper side of 1 in 4; the rear face, which is ashlar, descends vertically into a trench or

water cushion, hollowed out of the shale and lined with limestone masonry. This water-cushion is narrower than it should be. The coping is protected from floating timber by a foreshore of rubbish from the shale excavation. This branch is adapted for a depth of 6 feet of water down to the first drop lock in the 118th mile. Below that lock, water is passed, for a limited extent of irrigation, round ten locks, and at the eleventh lock (130th mile) all irrigation ceases. The canal between the 118th and the 146th mile consists of level reaches adapted for a depth of 5 feet of water, and contains seventeen locks, with a total fall of 187 feet 6 inches, and a maximum fall in any one of 14 feet. The bottom breadth throughout is 50 feet.

The third branch irrigating channel takes its supply from the main stream in the Koondêr at Rājōli. The 146th mile of the navigable canal falls into this branch about $\frac{1}{4}$ mile below its head, and is continued to the 180th mile. The Rājōli weir is of solid limestone in coursed rubble masonry, 5 feet thick at the top, with a batter of 1 in 2 on the upper face and plumb on the lower face. (Fig. 6.) It stands on thick beds of solid limestone. With a depth of 5 feet of water in it, the canal will discharge 50,000 cubic yards of water an hour, the bottom breadth being 50 feet. The irrigating channel ceases at the first lock in the 172nd mile, and thence to the river Pennêr is a still-water canal, which falls 90 feet 6 inches, by means of nine locks, of which the greatest drop is 13 feet.

The fourth branch is a length of 8 miles of canal at nearly a level, supplying a small area of irrigation. It is, in fact, the first 8 miles of the projected continuation of the canal into Nellore. It is adapted to distribute for irrigation about 5,000 cubic yards an hour of water, and has a bottom breadth of 50 feet. The headworks consist of a weir¹ across the main supply in the Pennêr, with head and under sluices, and entrance lock. The river gates of the entrance lock are 25 feet high, and are the heaviest on the canal. The weir for a short portion of its length is of solid limestone in rubble masonry founded on rock; but the greater proportion of it is founded on sand, and consists of a masonry slope supported on the upper edge by a double row of wells and on the lower edge by a single row of deep wells. There is a longitudinal row of wells along the middle also. The slope is 1 in 11.75; and below the

¹ Mr. H. P. Higginson, M. Inst. C.E., has presented to the Institution a description of this weir. It was not possible to read this communication during the Session 1871-72.

slope is a dry rubble apron 105 feet broad. The canal terminates at a distance of $1\frac{1}{2}$ mile from the Madras railway, and 163 miles from Madras.

Besides the weirs, some of the masonry works on the canal deserve notice. The Hindry aqueduct carries the canal 90 feet broad and 8 feet deep over the Hindry, at an elevation of 32 feet, by fourteen 40-foot arches, the length between the abutments being 651 feet. The lowest headway, at full water, under any bridge over the canal, is 15 feet; the smallest width, in locks is 20 feet. The under bridges have a width of 30 feet, except in two cases, where it is 25 feet. The lock chambers are 20 feet by 120 feet in the clear, and are adapted for working with a depth of 5 feet 6 inches of water, though they will work with less. The filling and emptying sluices are a pair to each pair of lock gates, *i. e.*, four to each single lock. Each sluice has an opening 4 feet square, and the ratio of the inlet ports to the sluice and to the outlet ports is as 5, 4, and 8 respectively.

The grade or fall of the canal where it is taken down the irrigating channel varies between 18 inches a mile in one or two deep cuttings, and a level in the tanks formed where the canal is carried over an open valley, by damming it across. In other places it is usually from 4 to 6 inches a mile. The last seems to be the most suitable fall where the cuttings and banks are of cotton soil unprotected by revetment of any sort; but it is impossible, without further experience, to say whether a more rapid fall would not be better. The more rapid the fall, the less silt will be deposited, but the more current there will be against ascending boats. Hitherto the silt has given but little trouble, and it seems likely that an annual outlay of £1,000 will suffice to remove all deposits of silt.

The lock sluices are simple cast-iron shutters running on wheels 8 inches in diameter. When quite closed, however, the shutter bears on the cast-iron frame or seat. They readily are raised by a rack by two men in a few seconds, or by one man where balance weights are attached.

No measuring sluices are needed. Two sizes of sluices for irrigation are used, besides some small ones, closed by hand, in the first three sections. The smaller size is 18 inches wide and 1 foot-lift, worked by turning round a vertical screw lifting a cross-head, to which the cast-iron shutter hangs. The larger has a lift of 3 feet 9 inches, and is 5 feet broad, the shutter being made of wood; and it is raised in the same way as the smaller ones. Each turn of the screw raises the shutter 1 inch, and one man can easily

work it against an average head of water of 6 feet. The raising gear and cast-iron grooves of the larger size cost £11 4s., delivered in London on board ship, and the smaller size, including iron shutter, £5 7s. The lock valves with crab, shutter, and frame complete, cost £36 each; while the gates complete in place cost about £2 11s. per foot drop.

Though the masonry works, and especially the weirs, contain a great variety of work, the chief interest and novelty in the construction of the canal is, undoubtedly, the mode of forming the banks. These range up to a height of 50 feet from the ground surface of their site to the water line. They are upwards of 35 feet in total height in the 13th, 18th, 22nd, 23rd, for nearly half the 24th, 29th, 32nd, 33rd, 34th (in these last 2 miles $\frac{1}{2}$ mile of bank is 40 feet high), 48th, 54th, 58th, and 63rd miles; while in the 26th and 27th miles the bank exceeds 40 feet high. These banks are always on sloping ground, so that the height above the outer toe is more than the nominal height. Their formation in the above cases is as follows (in all cases the single bank is reveted or shingled on the inner slopes):—

Simple filling only in miles 5, 13, 22, 23, and part of 24, 32, 40, 54, 58, 63.	
Masonry wall, Fig. 7, in miles	24, 26, 28.
" face wall, Fig. 8, in miles	26, 27.
" revetment, Fig. 9 "	18.
Puddled bank, Fig. 10 "	24, 33, 34.
Puddle core bank, Fig. 11 "	26, 29.

The banks of the sections Figs. 7, 9, and 11 came into the Author's hands in 1865, as finished works, but have since been strengthened or raised. In Fig. 7, the rear wall is almost superseded by the backing of dry rubble added behind, so that the front wall acts as a face-wall to the mass of rubble behind. This is found a very efficient kind of wall; but it is right to mention that a portion of wall of this section was carried away during an extraordinary flood in August, 1870, which rose over the wall and, probably, cut down the ordinary bank at its junction with the end of the wall. The bank represented in Fig. 11 was originally constructed—as shown by the dotted lines—without the foreshore of puddle, and with merely a vertical central core of puddle 9 feet thick, extending from top to bottom, between two slopes of hand-packed rubble. The objection to this proved to be that the vertical core, being held by the packed rubble walls, could not settle. Hence if, on first filling the canal after a dry season, the water penetrated through some crack in the core, it would extend the crack, by wearing it wider

and deeper ; while the puddle above would stand in an arch. No breach ever occurred from this cause, but excessive leaks took place in two cases, before the cracks could be reached through the hard puddle above them. A puddle foreshore was therefore added, in a position more easy of access than the puddle core.

The strongest and best sections are those shown in Figs. 8 and 10 ; sections adopted after the experience of two seasons in the working of banks of all kinds. The Author estimates the efficiency of these as so nearly equal, that the choice between them may be a question of cost. The only objection to the face-wall is that the bank cannot be raised, when once the wall is built, without carrying up the wall to a narrower width than 2 feet, or at least increasing the weight on the original wall by the addition of the material required to raise the bank. Hence, if enlargement of the canal be anticipated, the wall has to be built of a stouter section from the first. No portion of this face-wall has cracked or shown any signs of weakness ; nor, though unprotected in front by either plaster or puddle, is the leakage more than just sensible. The puddled slopes are even tighter than the face-wall, and have proved efficient even when the bank is of the worst kind of white and grey clay, mixed with salts of lime and soda, and such as to absorb water readily. It may be thought more liable than a wall to injury from vermin, but no difficulty nor accident has yet occurred, and any defect is more readily repaired, and is less dangerous than in a wall ; and this remark applies to defect from bad workmanship as well as from external violence. The total length of masonry walls in the banks is but a few chains short of 5 miles, and the puddled banks are nearly of the same extent.

In estimating the probable stability of a bank composed of soil thrown up, without either selection or puddling, when first exposed to water, a few first principles require to be borne in mind. Failure will take place either from the soil taking a flatter slope, when acted on by the water, than it originally stood at in the bank, or from leaks forming holes through the bank and ultimately destroying it. The Author has successfully stopped leaks 2 feet 6 inches in diameter, occurring at a height of 12 feet above the ground ; and, on the other hand, has had the rear of a bank slipping down to a slope of about 1 in 10 also readily repaired. A little consideration will show how such casualties may be best treated ; and lastly, how, by a careful construction of the bank, they may be avoided altogether.

It is necessary, in treating failures of banks, to get rid of the notion that, in practice, soil acted on by water becomes really

viscous, *i. e.*, chemically semi-fluid. The action of water for all practical purposes is mechanical. It is true that the presence of salts causes dry earth rapidly to absorb water to which it may be exposed; and the subsequent deliquescence of the contained salts may leave the soil in a thoroughly boggy state. But such soil only requires mechanically draining (perhaps no easy matter) to restore it to firmness; and it will then be freed from the salt, which will have been carried away in solution. The flattest slope taken by dry material is probably that of ground quick-lime, as it runs dry from the grindstones, when it will run nearly flat; and generally the natural slope at which dry material, deposited at hap-hazard, will stand is steeper in proportion as the particles are angular and rough, and flatter in proportion as they approximate to polished spheres; in the former case hardness of each particle or piece secures a maximum steepness of slope, in the latter case a minimum. The effect of a little moisture is virtually to increase the roughness of the particles, supposing no chemical action; the cohesion of small surfaces in contact being increased so much, that if the particles are small the material may stand vertically when damp, or at an overhanging slope. Excess of water may have, however, a very different effect, which will depend on the nature of the material. Thus a mass of rubble or gravel consists of materials of such a size as to be unaffected by the presence of water, as far as regards the relative position the particles are disposed to take; except only when the flood of water is so violent as to displace them by mere force of impact. Again, clean sand may be defined as a collection of insoluble particles, so small that, though after being thoroughly wet much of the water, if allowed, will drain out of it, yet enough will remain to increase cohesion, and so much as to equal or exceed the force of gravity on any particle. But clayey earth has its particles so fine as to retain by cohesion a sufficient quantity of water to separate, or nearly separate them, and to render the mass apparently viscid; and so it will remain until the water be squeezed out by pressure or dried up by heat. It may require intense pressure or heat to render such a material really dry; but a moderate amount of either may render it very hard. When really dry, the material will have become stone, or so like stone that the particles will not separate if again exposed to water; but if only moderately dry, as it is found in banks, it is possible that, when water is admitted into the crevices or pores of the material, it may so loosen the particles as to make them easy to separate, and unable to resist the slightest action of running water. This may happen even while the

cohesion remains so strong as to check and practically resist the passage of water through the body of the material.

The two dangers of slips and leaks to which a bank is exposed, and the mode of meeting them, are the following. In the first place water may be forced by pressure into the accidental interstices or fissures in sand or clay faster than it can drain or dry out of it; as where the outer slope of a leaky bank is made of sand, or where a bank is thrown up entirely of moist clay, and the greater weight on the centre squeezes out water contained in the central portion and forces it into the slopes. In both these cases slips of the slopes are likely; and they take a flatter slope than that at which they first stood. The danger from leaks is when water obtains a free passage, either through a crack or a burrow, without meeting any resistance sufficient to hold it back against the head under which it advances. The action of such a stream may enlarge the opening until the bank is destroyed. To stop a slip, either the water must be tapped by a drain before it enters the slope, or the slope must be artificially supported by a weight sufficient to prevent its movement. In the case of water flowing through a crack or burrow, no danger will result unless the material be tough clayey soil. A sandy soil soon falls in, as

Fig. A.

Fig. A will show, for the bed of the cavity will absorb the water, and the material will run to so flat a slope, and the sides, right and left, will be undermined so fast, that the top will fall in from the surface of the bank before it can attain any magnitude. In a tough loamy clay a crack is much more dangerous, for the soil is nearly impervious, and the stream will simply soften and carry away the bottom and sides of the burrow with which it comes into actual contact (Fig. B), and may cut its

Fig. B.

way down without widening the cavity sufficiently for it to fall in, even though it meander about and cut caverns 5 or 6 feet in diameter. The quicker the stream the more vertically the sides will stand; so that a leak of long standing is generally found to have cut a steep, narrow way nearly down to the level of the ground near the centre of the bank, and then to have made a series of wide chambers on its less rapid passage to the rear. Such leaks are best stopped by filling the caverns in the rear with gravel or rubble, and at once cutting

down to the leak on the water side of the bank, and puddling it up on that side.

But the real problem is to make a bank which can neither slip nor be cut up by leaks; and may be safely filled after being dried for a couple of months by a mean daily temperature of 98° Fahr. in the shade, that of evaporation being 70°.

The consideration of this problem is the more necessary owing to the wholesale condemnation of earthen dams of above 65 feet in height, by M. Graeff, Engineer in Chief of the Ponts et Chaussées, in 1866.¹ This condemnation is disproved by the long existence and security of the dam of Cumbum, 102 feet high, under 94 feet depth of water. It may however be interesting to show, that a scientific and practicable theory exists for the construction of earthen dams; and it only remains to bear in mind, that a given quality may be secured, with less risk of defective work, in earth-work, with at least as much certainty as in masonry.

Before a bank can be safely exposed to water as above, the following conditions must be satisfied:—

1. The greatest possible leakage must not carry any material out of the bank.

2. It must be impossible for any burrow or crack to be made right through the bank.

3. The impervious part of the bank must be secured in its place, so that neither settlement can breach it, nor leaks through cracks which will occur in it carry the material out of place.

4. The impervious part must be encouraged to settle or shrink so as to close any cracks which may occur in it.

5. It must be easy to detect and overhaul any bad puddle.

It will be found, in practice, that when a bank fulfils these conditions, the entrance of water into any part of the bank is more difficult than its exit, and that in consequence the head of water upon the bank tends to press upon and tighten up every layer of material in the bank—a result that tends very much to increase the stability of every part.

¹ “It is not necessary to consider the plan of constructing dams of earth, which are things of chance when they attain a height of 20 mètres (65·6 feet), and it is out of the question to use this construction for a height of 50 mètres (164 feet), which we have now under consideration.”—Fife's translation of Graeff's Report* on the Dam of Furens, &c., in “Selections from the Records of the Bombay Government—Irrigation Series.—No. ix.” 8vo., Bombay, 1869.

* This Report appeared in the “Annales des Ponts et Chaussées.” 4^e Série. Tome xii. pp. 184–211. 8vo., Paris, 1866.

[1871-72. II. N.S.]

It may be well to consider first how a bank should be theoretically constructed without any puddle at all; and, for this purpose, as round numbers are convenient, a bank 200 feet high will be taken merely as an illustration. It may be observed, to start with, that though the theoretical conditions of quality and arrangement of soil may not be absolutely attainable in practice, yet the margin of safety is so large, and the modifications permissible so ample, that any condition of security can, in fact, be attained in practice. Again, it is well to premise, that not only clean sharp sand and small gravel, but also these materials, after having their interstices silted up with a tough matrix of clay or puddle, present an insurmountable obstacle to the burrowing of vermin and to cracking by heat.

Let Fig. 13, Plate 16, represent a vertical cross section of a perfect filter in a prismoidal or wedge-shaped trough, whose sides contain an angle of 60° . By its being perfect, let it be understood that, whatever depth of water be placed upon it, the water alone moves as it passes through the filter; and that the material of the filter is arranged in horizontal layers, beginning with fine sand at the top, and then becoming successively coarser until the lower angle contains large rubble blocks, in such accurate proportion that the water flows through freely enough not to resist that behind it, but not so freely as to leave any apertures.

If the upper layer of fine sand be as deep as the water placed upon it, and be clean, the quantity of water flowing through the filter, or, in other words, the leakage, would be usually calculated at 700 gallons per day for each square yard of surface; which, for the filter in the figure 200 feet high, would give $13\frac{1}{2}$ cubic yards of leakage an hour per lineal yard of filter; an amount so small that it would flow away in a stream an inch deep, with a velocity of little over a quarter of a mile an hour. And this leakage would represent the work done by 200-feet head of water, in forcing a passage for such a stream through the obstruction presented by the filter, and imparting to it the velocity with which it issues from the lower edge.

If this prismoidal filter be supposed to be laid on its side upon an impervious soil, and the casing containing it be removed and replaced by slopes of fine sand in front and of filling in rear, care being taken to keep open a drain of dry stone, or of masonry arches, from what was previously the lowest edge of the filter (Fig. 14), the result is a bank so constructed as to fulfil the five conditions already stated for a safe bank, but without any puddle. The higher the bank for a given coarseness of sand, and

the thinner the layer of sand forming the front slope, the more water would flow through the bank; but even if the leakage increased a thousand times, and the water poured from the rear of the bank like the back lash of an Atlantic storm wave, there is no engineering difficulty in securing the rear so that the water should pass out without disturbing the outer toe of dry rubble blocks; and if these do not move, no particle in front of them can be displaced, by hypothesis, except by actual crushing of the material. It will be observed that no crack nor burrow can be made in the material of this bank, either by sun or vermin; and that it only needs its surface protecting from the action of rains and waves to form a durable bank.

In the Author's opinion, there is no other sound and safe principle on which earthen banks of tanks or reservoirs can be constructed except that described. In practice, puddle is added to stop the leakage, and the durability of the bank is thereby also increased. But a reservoir bank can hardly be considered safe if, owing to the mode of its construction, a crack, burrow, or other leak through the puddle, would be dangerous to it. In practice, the best position for the puddle is on the flattest slope in front of the bank (Fig. 10), where it should be protected by rubble, the larger and smoother the better, laid on sharp loose gravel impervious to vermin. The thickness of this protection must be so great that it cannot be wholly removed as the bank settles. Rubble packed, or very rough stone, as kunkur, is best avoided; since it will not follow the bank during settlement: hence the dry rubble facing must be thicker as the bank is higher. Unless there be liability to a scour along the inner toe, there is no occasion to make it thicker at the bottom than at the top, but rather the reverse, since the waves will be heaviest when the tank is full. The puddle will be the most dense part of the bank. Where used by the Author, the surface of puddle under construction is kept always flooded, like a rice field; and gangs of men, with their arms linked together, walk backwards and forwards on short lengths of it all day, treading it stiff to a song, as layer after layer is added by the workmen. The thickness of puddle used for banks under 40 feet high is just 1 foot thinner than that used in the bank of the Sheffield Waterworks Company, which did so much damage by bursting on the 11th of March, 1864; *i. e.*, it is 3 feet thick at the water-line, and increases at the rate of 1 foot in thickness for every 8 feet vertical depth below the water-line. The puddle must, if necessary, be carried down in a trench—sheet piling also being added if necessary—so far as to prevent any flow of water below

it being so violent as to displace material, or so copious as to be wasteful.

In order to insure the puddle remaining watertight under all circumstances of original settlement, and of alternate wet and drought, it is desirable that it should rest on a substance rather more compressible than itself. To lay it at once on ordinary rammed filling would be too violent a change; and it has always been laid by the Author on a cushion of earth moistened and rammed; each layer, of 6 inches or so, being well wetted and then sprinkled with enough dry earth to prevent it sticking to the rammer, when punned with a rammer of 40 lbs. weight. The rest of the front slope, if not already existing, has been made of earth rammed dry in the usual way; since it was found safest, indeed almost necessary, to establish the broad rule, that nothing but earth should be brought to the front of the centre line of the bank. The bank was then completed with any gravel or bad soil available, the gravel being kept at the bottom as much as possible, and the finest soil to the centre. Though such banks are not theoretically perfect, they have never failed nor given trouble upon letting the water against them. The lengths entirely constructed on these rules are insignificant, but about 5 miles of old bank have been faced with puddle laid on earth rammed moist.

The form recommended by the Author for higher banks is shown in Figs. 15, 16, and 17, which only needs a remark, that where the bank runs out on a hill-side, or the ground along the centre line of the bank rises or falls, the water which leaks through and under the puddle will be liable to run along inside the bank, instead of escaping out of the rear toe at once. Hence, at the deeper parts of the bank, larger stone is desirable at the outer toe, whatever other artifices the nature of the ground may admit of.

The greatest average monthly progress in any year made on the Soonkêsala and Cuddapah canal was 273,000 cubic yards of earthwork and 11,572 cubic yards of masonry, in the working season, April to March, 1869-1870; but this could be exceeded were labour concentrated in one spot and assisted by machinery.

The cost of earthwork varied from 2*d.* to 6*d.* per cubic yard; of rock cutting, from 6*d.* to 2*s.*; and of rubble masonry, from 5*s.* to 10*s.*, the latter including a little cut stone.

Much rubble masonry, including arch work, was done in aqueducts and bridges, as in the whole of the 9th section of the canal, at the rate of 8*s.* a cubic yard over all, with centerings found. Earthwork in black cottonsoil 6 feet deep, or thrown

into banks, was done rapidly during the year 1870, at $2\frac{1}{2}d.$ a cubic yard.

The actual cost of the first 75 miles of canal—the length whose main office is to carry water for distribution below—has been £8,710 per mile, including headworks. The next 115 miles, including locks and all works, has cost £2,900 per mile; and the whole canal, including the expensive weir across the Pennêr, has cost £5,260 per mile. These rates include all English stores and plant used for the work; but to cover the cost of engineering, management, and stores in stock never issued for use, 50 per cent. requires to be added to the above figures.

The powers of irrigation possessed by the canal, as it at present exists, admit of a clear but not very precise definition, owing to the number of contingencies for which it is adapted, but which are not yet determined by experience. If rice alone be considered, the irrigating power possessed by the canal, estimated at 2 cubic yards of water an hour per acre where the waste water is lost, and $1\frac{1}{2}$ cubic yard where it is again taken up by the canal below, is—

In the Toombuddra Basin	50,000 acres.
„ „ Caulee „	30,000 „
„ „ Koondêr proper	100,000 „
„ „ Pennêr „	3,300 „
Total	183,300 „

To which can be added, at an expenditure of 2s. an acre—

In the Caulee Basin	17,000 acres.
„ „ Koondêr proper	50,000 „
Grand total	<u>250,300</u> „

Since the supply amply suffices for growing a second crop of wheat for every acre of rice, and it is already found that this cultivation is commencing, during the first season of the canal being opened throughout, the revenue possible at the present water rate of Rs. 6 an acre, and assuming no first crop irrigated except rice, is £300,000; and the yield, at the average yield of five years under tank irrigation in the Kurnool district, would be above 300,000 tons of rice grain, and about 500,000 tons of rice straw, and about a third of that weight of wheat and wheat straw; quantities which could be increased by the importation and use of manure. But in order to grow so much rice, the irrigation of dry

crops, such as indigo, cotton, &c., would have to be neglected; though the demand for irrigating such crops is, so far, as extensive as that for rice.

In reference to navigation, the capability of the canal seems ample; and it may be necessary to explain the reasons for this. The Board of Directors were desirous of commencing with locks of a smaller size—more like the inland locks on English canals—but at the desire of the Madras Government, expressed in 1866, this was given up. Supposing the accommodation for traffic on the canal to offer no greater attractions to the native public than that of a railway, the weekly traffic may be estimated as equal to that on the N.W. line of the Madras railway when open to Muttonpullu—or say £5 per mile a week. If to this be added the immense traffic created by the canal itself, more than equal to the whole then traffic of the N.W. part of the Madras railway, the result will be as follows :—

The total population of the districts through which the canal passes is about 700,000; a population capable of consuming annually $127\frac{3}{4}$ million measures of rice if they ate nothing else. The possible yield of grain is 250 million measures of rice, and $83\frac{1}{2}$ million measures of wheat. Supposing that 250 million measures of grain are not eaten by the local population, the only means of getting rid of them freely is by the canal, and this gives, at 3 lbs. a measure, above 300,000 tons. If this quantity be carried annually over half the length of canal, it gives a daily traffic of 500 tons a mile every working day; to this must be added straw, manure, and the commodities purchased by the sale of the product, besides all the traffic which a railway would have, as above estimated.

But a brief comparative sketch of the Madras Irrigation and Canal Company's canal between Soonkêsala and Cuddapah, and of the Grand Junction canal between Brentford on the Thames and Braunston, will give as good an impression of the work as any technical description can do.

The Grand Junction main canal is $90\frac{1}{4}$ miles long, $4\frac{1}{2}$ feet deep, 36 feet broad at the top, and 24 feet broad at the bottom. The Soonkêsala canal is 190 miles long, of which 75 miles are never less than 100 feet in average breadth, nor 8 feet in depth, and average about 253 feet breadth at the top, and 9 feet in depth. The locks in the English canal are 86 feet long by 15 feet wide; in the Soonkêsala canal 120 feet by 20 feet, or nearly twice the size. The navigable branches of the Grand Junction are 28 feet, and even 20 feet broad at the water level; while the narrowest por-

tions of the Soonkêsala canal are 70 feet, or, for a few miles, 65 feet. The former has one hundred and two locks, averaging $7\frac{1}{2}$ feet rise; the latter has only forty-seven locks (reckoning double ones as two, and besides three level floored locks), averaging $9\frac{3}{4}$ feet rise. The former was commenced about 1795, and was completed as follows: 15 miles were opened up to November, 1797; $28\frac{1}{2}$ miles more were opened in June, 1798; $20\frac{1}{2}$ in 1799; $25\frac{3}{4}$ in 1800; $6\frac{1}{2}$ in October, 1800, and 3 more, including the Blisworth tunnel, in March, 1805; making, with the Paddington branch opened in 1801, a total of $102\frac{1}{4}$ miles completed in ten years, at a cost which ultimately reached about £2,000,000. The Soonkêsala canal, 190 miles long, was commenced in October, 1861, and was all brought to completion, as required by the Company's engagement with the Government, in June, 1871, or in about ten years, at a cost which, when it includes wharves and floating stock, will reach about £1,750,000. It would probably have been better had the Grand Junction canal been originally constructed of the size of the Soonkêsala canal; for, though it worked profitably to itself—so much so that its £100 shares rose to above £200—yet it proved too small to accommodate the traffic it developed, and has therefore sunk for the present under the competition of the railways. It is interesting to compare the size of the towns affected by the two canals at the time of their opening. London had then 864,845 inhabitants; Madras has about 760,000. Northampton had 7,020; Derby, 10,832; Dudley, 10,107; Walsall, 10,400; and Birmingham, 73,670. Kurnool has about 12,000; Cuddapah, 25,000; Nundial, probably 7,000 or 8,000. Again, the producing and manufacturing powers of the two districts are strikingly similar, though in contrast. The Grand Junction canal promoted the production of coal, iron, and lime from below the earth's surface, and the industrious manufacture of exotics by machinery; the Soonkêsala canal cannot but promote the production of material for food, clothing, and luxury upon the earth's surface, and the manufacture of food, cloths, colours, paper, &c., for which the Madras Presidency was formerly celebrated over the whole of Europe and Asia; and for this work the population is likely soon to be adequate.

Not only corn-fields, but also gold-fields, are far better off in a climate of prolonged settled weather and short heavy rains than in one of comparative uncertainty. It is far better for the gold-digger to have a store of water with which he can work during dry healthy weather, than to have to work in an uncertain climate where he is liable at any time to be flooded out or left dry.

It is satisfactory to find that, while the Governments in India

are becoming alive to the value of irrigation in the centre of India, those of Australia are seriously considering the same subject; and it may be hoped that the English nation will not long be behind the Hindoo, the Italian, and the Spaniard in irrigation, as they at present are.

The communication is accompanied by a series of diagrams, from which Plates 14, 15, and 16 have been compiled.

PLATE 14.

THE SOONKÉSALA CANAL MADRAS IRRIGATION AND CANAL COMPANY.

PLATE 15.

Scale for Figs 3, 4, 5, 6 & 11. 12 Feet = 1 Inch.
0 10 20 30 40 50 60 70 Feet.

Scale for Figs 7, 8, 9 & 10. 24 Feet = 1 Inch.
0 10 20 30 40 50 60 70 Feet.