elevations *in cumulo* by groups of locks at places where it can be most advantageously done. This leads to a saving of attendance and expense in working the canal, and causes fewer stoppages to the traffic. But to prevent waste of water the locks must be placed sufficiently far apart, say 100 yards, or an intervening pond or increased width of canal must be formed, so that a descending boat does not let off more water than the area below will receive without raising its surface so much as to lose the surplus water over the waste weirs. The mode of overcoming the difference of level between the various level reaches is, with few exceptions, by locks, which generally have a lift of 8 or 10 feet, though in some cases it is somewhat greater. The dimensions of the locks ought to be regulated by the traffic; but they should, in order to save water, be as nearly as possible the size of the craft to be passed through them, allowing from 6 inches to a foot of extra breadth and draught of water. The barge-canals in England have locks about 8 feet in breadth, and from 70 to 80 feet long, and their use in raising or lowering boats from the different reaches is so well known as not to require explanation; and for details as to the construction of the masonry of the chamber and walls, and the timber and iron work of the gates and sluices, reference is made to "Rankine's *Engineering.*" The water is generally admitted into and flows from each lock by sluices formed in the gates, and the passage of a boat occupies from three to six minutes, depending on the lift. Sir William Cubitt, on the Severn navigation, introduced the water through a culvert parallel to the side wall of the lock, and opening in the centre by means of a tunnel, which admits of 16,000 cubic feet of water flowing into or out of the lock in $1\frac{1}{2}$ minute; and in little more than that time loaded vessels can be passed through.[1]

Inclined planes.

Inclined planes and perpendicular lifts, which have the advantage of saving water, were adopted so long ago as 1789 on the Ketling Canal in Shropshire, and afterwards on the duke of Bridgewater's canal. Mr Douglas of New York constructed the Morris Canal in the United States with 23 inclined planes, having gradients of about 1 in 10, with an average lift of 58 feet. The boats weighed, when loaded, 50 tons, and after being grounded on a carriage, were raised by water-power up the inclines with great ease and expedition. The length of the Morris Canal, between the rivers Hudson and Delaware, is 101 miles, and the whole rise and fall is 1557 feet, of which 223 were overcome by locks, and the remaining 1334 by inclined planes.[2] When first describing this work the author stated that the principal objection to the inclined planes for moving boats was the injury they were apt to sustain in supporting great weights while resting on the cradle. A slimly-built canal boat, 80 feet long, and loaded with 30 tons, could not be grounded on a smooth surface without straining her timbers, but this objection has to some extent been overcome on an inclined plane constructed by Mr Leslie and Mr Bateman on the Monkland Canal, where the boats are not wholly grounded on the carriage, but are transported in a caisson of boiler-plate containing 2 feet of water, and are thus *water-borne.* This inclined plane is wrought by two high-pressure steam-engines of 25 horse-power each. The height is 96 feet, and the gradient 1 in 10. The maximum weight raised is 80 tons, and the transit takes about ten minutes. The average number of boats passing over the incline is about 7500 per annum. Mr Green introduced on the Great Western Canal a perpendicular lift of 46 feet. Sir W. Cubitt also introduced three inclined planes, having gradients of 1 in 8, on the Chard Canal, Somersetshire. One of these inclines overcomes a rise of 86 feet; and they are said to act very satisfactorily.[3]

An essential adjunct to a canal is a sufficient number of waste-weirs to discharge surplus water accumulating during floods, which, if not provided with an exit, may overflow the tow-path, and cause a breach in the banks, stoppage of the traffic, and damage to adjoining lands. The number and positions of these waste-weirs must depend on the nature of the country through which the canal passes. Wherever the canal crosses a stream a waste-weir should be formed in the aqueduct; but independently of this the engineer must consider at what points large influxes of water may be apprehended, and must at such places not only form waste-weirs of sufficient size to carry off the surplus, but form artificial courses for its discharge into the nearest streams. These waste-weirs are placed at the top water-level of the canal, so that when a flood occurs the water flows over them and thus relieves the banks. The want of these has occasioned overflows of canal banks, attended with very serious injury to the works, and lengthened suspension of the traffic; and attention to this particular part of canal construction is of essential importance.

Stop-gates.

Stop-gates are necessary at short intervals of a few miles for the purpose of dividing the canal into isolated reaches, so that in the event of a breach the gates may be shut, and the discharge of water confined to the small reach intercepted between two of them, instead of extending throughout the whole line of canal. In broad canals these stop-gates may be formed like the gates of locks, two pairs of gates being made to shut in opposite directions. In small works they may be made of thick planks slipped into grooves formed at the narrow points of the canal under road bridges, or at contractions made at intermediate points to receive them. Self-acting stop-gates have been tried, but their success has not been such as to lead to their general introduction. When repairs have to be made stop-gates allow of the water being run off from a short reach, and afterwards restored with comparatively little interruption to the traffic. Their value in obviating serious accidents has been well exemplified in the author's own experience. The water during a flood flowed over the towing-path of the Union Canal connecting Edinburgh and Glasgow, and the uncontrolled current carried away the embankment and the soil on which it rested to the depth of 80 feet, as measured from the top water-level. The stop-gates were promptly applied, and the discharge confined to a short reach of a few miles, otherwise the injury (which was, even in its modified form, very considerable) would have been enormous, not only to the canal works but to the adjoining lands.

Offlets.

For the purpose of draining off the water to admit of repairs after the stop-gates have been closed, it is proper to introduce, at convenient situations, a series of exits called "offlets," which are pipes placed at the level of the bottom of the canal, and fitted with valves which can be opened when required. These offlets are generally formed at aqueducts or bridges crossing rivers, where the contents of the canal can be run off into the bed of the stream, the stop-gates on both sides being closed so as to isolate the part of the canal from which the water is withdrawn.

In executing the work, provision must be made for the proper drainage of the tow-path, which should be made highest at the side next the canal, and sloped with a gentle inclination towards the outside. The drainage of the tow path should be carried to a sky drain, and at intervals passed below it into the canal, as shown in fig 3.

[1] *Minutes of Proceedings of Institution of Civil Engineers*, vol. v. p. 340.

[2] Stevenson's *Sketch of Civil Engineering in North America*, London, John Weale.

[3] *Minutes of Proceedings of Institution of Civil Engineers*, vol. xiii p. 205.

The preservation of the banks at the water-line is also a matter of importance. "Pitching" with stones and "facing" with brushwood are employed, and in the author's experience the latter, if well executed, forms an economical and effectual protection.

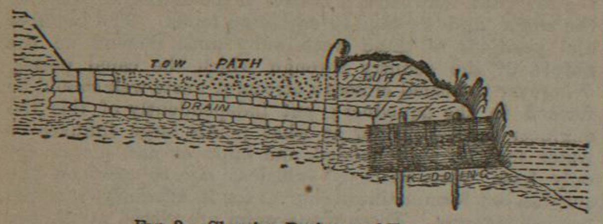

FIG. 3.—Showing Drainage of Tow-path.

Puddling.

In forming the *alveus* or bed of the canal care must be taken, especially on embankments, and even in cuttings where the soil is porous, to provide against leakage by using puddle, as shown as fig 2. An all-important matter, as affecting the construction of the works, is the possibility of getting clay in the district, or such other soil as may be worked into puddle, on the good quality of which the stability of the reservoir embankments and the imperviousness of the beds and banks of the canal mainly depend.

These are the only points of general application, in the construction of canals, to which reference can here be made; and in applying them to each case the engineer must be guided, *first*, by theoretical knowledge, to be acquired by a careful study of his profession; and, *secondly*, by that knowledge which can be gained only by experience.

Mode of conducting traffic on canals.

Not a little has been written on the best mode of conducting traffic on canals, and the reader who wishes to study the subject fully is referred to the observations made by Mr Walker and Mr George Rennie in the *Transactions* of the Royal Society and of the Institution of Civil Engineers, and especially to the valuable researches on hydrodynamics by Mr J. Scott Russell in the *Transactions* of the Royal Society of Edinburgh. Mr Russell while experimenting on propelling boats at high speeds found that the primary wave of displacement produced by the motion of a boat moves with a velocity due to the depth of water in the canal, being the velocity that is due to gravity acting through a height equal to the depth of the centre of gravity of the cross-section of the channel below the surface of the fluid. The velocity is in no degree dependent on the form or velocity of the body which generates it, or on the breadth of the canal. A wave that had a velocity of 8 miles an hour was traced to a point where the channel became deeper, and its velocity was suddenly accelerated; the channel became alternately narrower and wider without producing any sensible effect, but when the wave once more reached that part of the channel which was of the original depth it resumed its original velocity. A fact of great practical value was established, that a boat, if raised by a sudden effort to the top of a primary wave, could be drawn along at 10 miles an hour with less fatigue to the horses than if drawn at the rate of 6 miles, while the waste was less severe on the banks of the canal. These investigations were made before the general establishment of railways, when swift canal travelling seemed a desirable attainment. But though *boats* propelled at high speed on canals have given place to *railway carriages*, yet the canal traffic at slow speeds must be conducted, and the cheapest means of effecting the "haulage" with the least danger to the banks is still an important inquiry, and has within the last few years afforded matter for some highly interesting papers and statements in the *Proceedings* of the Institution of Civil Engineers. These are communications on the employment of steam-power on the Gloucester and Berkeley Canal, by G. W. B. Clegram;[1] on the Grand Canal, Ireland, by Mr Healy;[2] on the Forth and Clyde, by Mr J. Milne;[3] and on the Aire and Calder, by Mr W. H. Bartholomew,[4] to all which reference is made.

One great objection to high speeds on canals is the wasting of the banks by the displacement produced in propelling the vessel through the water. The wasting, indeed, takes place even with very low speeds, and as a matter of canal engineering it is necessary to notice it. To give an instance of the effect on the large scale:—Mr Ure says that the river steamers on the Clyde, going at a speed of 8 to 9 miles per hour, produce a swell which commences to rise when the vessel is "2 or 3 miles off,"—a circumstance which was first noticed by Mr J. Scott Russell in 1837. The swell gradually increases as the steamer approaches, and at last becoming a wave of translation, it breaks on the river walls nearly abreast of the vessel, following her on her course along the river, as a violent breaking wave, measuring 8 or 10 feet from the hollow in the channel to the crest on the wall. A coating of heavy whinstone rock, from 2 to 3 feet thick, extending from low to high water-mark is found necessary to enable the banks to withstand it. Mr Ure also found that the action of passing steamers, though very destructive to the banks, was useful in stirring up the mud from the bottom, which was carried off by the currents to an extent which he estimates to be from 20 to 25 per cent. of the whole quantity dredged from one particular part of the river where he carefully measured it. It will at once be apparent, that however inconvenient these wasting waves may be in a river, the waves in a canal, though smaller, are nevertheless a source of greater anxiety, acting as they do in a narrow artificial channel, formed at some places on high embankments, the failure of which would be attended with serious consequences.

The wasting on canals where the traffic is conducted at a moderate speed is found to extend not more than 18 inches to 2 feet, that is 1 foot above and below the water-line, and Mr Clegram states that he has found on the Gloucester Canal that a facing of stone filled into a recess cut in the banks formed a complete protection. Brushwood, as already noticed, is also an effectual remedy.

Steam towing.

What has recently led to the consideration of the best means of protecting the banks of canals is the substitution of steam for horse power in working the traffic, which has been entirely successful. The first attempt at using steam-power on canals was made on the Forth and Clyde Canal with Symington's boat, in 1789. Various experiments were made to introduce tugs, but these were ultimately abandoned in favour of steam-lighters, which now in great numbers navigate the canal, and make passages to Leith, Greenock, and other trading ports on the Firths of Forth and Clyde.

Steam-towing on Gloucester Canal.

This system, however, would not suit the trade of the Gloucester Canal, which is chiefly frequented by sea-borne vessels, and steam-towing has been introduced on that navigation. The following extracts from Mr Clegram's paper[5] seem generally applicable to all navigations where towing is to be adopted. He says the ship canal leads from the Severn at Gloucester to the Severn at Sharpness Point. It is $16\frac{1}{2}$ miles in length, and has a depth varying from 18 to 18 feet 6 inches, navigable by vessels of 700 tons register. Prior to the year 1860 all sea-going vessels passing through were towed by horses, the number of horses being regulated by a scale varying from 1 horse for a vessel of 40 tons to 9 horses for a vessel of 420 tons. The cost of this amounted generally to about one farthing per ton per mile on the

[1] *Minutes of Proceedings of Institution of Civil Engineers*, vol. xxvi. p. 1. [2] *Ibid.*, p. 6. [3] *Ibid.*, p. 10. [4] *Ibid.*, p. 25. [5] *Ibid.*, p. 1.

register tonnage of the vessel. The speed varied from one mile to three miles per hour, according to the size of the vessel and the state of the weather.

In 1860 steam-tugs were placed upon the canal to do this work. They are iron boats, 65 feet long, 12 feet beam, and draw 6 feet 3 inches of water, fitted with high-pressure engines; the diameters of the cylinders are 20 inches, stroke of 18 inches, pressure of the steam 32 lb on the inch, and the cost of each £3000. Nearly the whole of the sea-going craft are now towed by these tugs. The vessels range from 30 tons up to 700 tons register, with a draught of water from 6 to 16 feet. They are towed either singly or in a team, according to circumstances. Sometimes as many as thirteen loaded vessels of from 50 to 100 tons register have been towed by one tug at the rate of 3 to $3\frac{1}{2}$ miles an hour. The heaviest load drawn by any one tug has been 1690 tons of goods in three vessels. Their draught of water varied from 14 feet 6 inches to 15 feet 6 inches, and they were taken the whole length of the canal at the speed of 2 miles an hour. The smaller vessels are towed at a speed of 4 miles an hour, to which as a rule they are restricted.

The employment of steam for towing has been found very advantageous. The vessels rub less against the banks, the power being right ahead, and not on one side as with horses. The wear on the ropes used in tracking is reduced, the speed is increased, and vessels can be moved along the canal in weather which would have prevented horses doing the work. With a strong wind athwart the canal vessels cannot be tracked *in train*; they must then be taken singly, or at most two at a time. When vessels are towed in train, as a rule the largest and heaviest draughted are placed first, and the hawser leading from the first vessel to the tug is taken from each side of the bow. With this arrangement, and a skilful management of the tug, the vessels can be kept *fairly* in the line of the canal.

The only disadvantage of this system, on a canal the sides of which are unprotected, is the additional wear caused by the run of water between the sides of the large vessels and the banks. Such vessels occupy a large part of the sectional area of the canal, and being taken along at a much greater speed than they were by horses the wash of water is more prejudicial. When the vessels or trains of vessels are heavy, and the tugs are working up to their full power and speed, the water thrown back by the action of the screw against the bow of the first vessel is thrown off by it to the banks on either side, and is the cause of considerable wash. This has been attempted to be remedied by placing the first vessel farther back from the tug; but in practice it is found that a distance of 40 to 50 feet is the farthest separation that can be allowed without sacrificing that *hold* between the two which prevents the vessel sheering from side to side. The first vessel being kept steadily in her course, the others follow without much difficulty.

The employment of tugs has afforded an unexpected facility for cleansing the canal from deposit of mud. Formerly it was difficult to remove this deposit from the slopes of the banks on which it collected, sometimes inconveniently contracting the capacity of the canal. Since the vessels have been moved at greater speed and *in trains* this deposit has been entirely removed from the slopes to the bottom of the canal, whence it can readily be taken out by the dredger.

But though all efforts to improve barge-canals can never bring them to compete with railways in the quick conveyance of passengers, it is surprising to find in how many places they still command an enormous traffic in goods and minerals, and thus act as a valuable relief to overburdened railways. This is specially the case in the manufacturing districts of England, where the Birmingham Grand Junction and other canals seem to carry on as brisk a trade as they did in days gone by when they had no competitors but the stage coach and the carrier's van.

These remarks, however, as to railway competition do not apply to Ship-canals, which, undisturbed by competing schemes, retain all the monopoly they ever possessed; and indeed, in the recent construction of the Suez and New Amsterdam canals, they have acquired an importance before unclaimed for works of that class—an importance which entitles them to the highest consideration in any engineering treatise; for, apart from their structural interest to the engineer, their usefulness in affording a short and sheltered passage for sea-borne vessels has long been acknowledged and can hardly be over-estimated.

The Languedoc Canal already mentioned, by a short passage of 148 miles, saves a sea voyage of upwards of 2000 miles through the Straits of Gibraltar. By the Forth and Clyde Canal sea-borne vessels, not exceeding $8\frac{1}{2}$ feet draught of water, can pass from opposite coasts of Scotland, through the heart of the country, by 35 miles of inland navigation and avoid the dangers of the Pentland Firth; the Crinan Canal substitutes a short inland route of 9 miles for a sea voyage round the Mull of Kintyre of about 70 miles; and the last great canal between Suez and Alexandria saves vessels a tedious voyage of 3750 miles on their route to India.

To most of the early ship canals that have been executed, the principles of construction already stated are generally applicable—the depth of water and dimensions of the locks and all other works being increased to suit the larger size of craft which use them, and therefore further notice of such details is not required. But having still to illustrate the larger class of works, we proceed to describe some of the largest of the ship-canals already constructed and projected, and in doing so, we shall consider ship-canals under the following three classes:—

Three classes of ship canals.

First, Canals which on their route from sea to sea traverse high districts, surmounting the elevation by locks supplied by natural lakes or artificial reservoirs, such as the Languedoc in France, or the Caledonian Canal in Scotland;

Second, Canals in low-lying districts, which are carried on a uniform water-level from end to end, and are defended against the inroad of the sea at high water by double acting locks, which also retain the canal water at low tide, such as the canals of Holland and other low countries;

Third, Canals, of which the Suez is the only example yet made, without locks at either end, and communicating freely with the sea, from which it derives its water supply.

The Caledonian Canal in Scotland is as good a specimen of works of the *first* class as can be selected.

In 1773 James Watt was employed to survey the country between the Beauly at Inverness and Loch Eil at the mouth of the river Lochy, a distance of about 60 miles, with the view of forming a ship canal between the two seas, to save about 400 miles of coasting voyage by the North of Scotland through the stormy Pentland Firth. The district referred to, called the "Great Caledonian Glen," as will be seen from Plate XXXVI., embraces a chain of fresh-water lakes, which, in connection with the surrounding glens, have afforded an interesting field for the speculations of the geologist; and no doubt the first conception of a canal through the district owed its origin to the apparent facilities for inland navigation which the lakes afforded.[1] In 1801 Telford was employed by Government to report, and the ultimate result of that report was the construction of the canal, which was opened in 1823.

The summit-level is at Laggan, between Loch Oich and Loch Lochy, whence the drainage flows to the Eastern and Western seas.

[1] *Life of Telford*: Caledonian Canal.