adequate, either in number or in power, for achieving the steepest ascending grades on any route, and no reduction in the number of animals will be practicable in the general case, in descending that or the lower grades, or upon the level portions of the line.

CHAPTER II.

EARTHWORK, DRAINAGE AND TRANSVERSE FORM OF COUNTRY ROADS.

Excavations and Embankments.

DUE regard to economy in the cost of constructing a road generally requires that its location shall be such that the cuttings shall balance the fillings, or in other words that the excavations, at points where the ground is higher than the road, shall furnish the contiguous *embankments* at points where the road is higher than the natural surface. Such, however, is not always the case, it being cheaper, under some circumstances, to deposit the excavations in *spoilbanks*, and procure the earth for embankment from *side-cuttings* near by.

The first location of the road upon the map will seldom be more than an approximation to the best line, which must finally be ascertained after successive approximations, for each of which a series of new sections must be drawn, and new calculations made. The contour lines referred to, of which an example is given in Fig. 3, or the parallel cross-sections as shown in Fig. 4, will be of great assistance in making these computations, and will materially abridge the labor of locating the line.

The "Lead."

Prof. Mahan says, "In the calculations of the solid contents required in balancing the excavations and embankments the most accurate method consists in subdividing the different solids into others of the most simple geometrical forms as prisms, prismoids, wedges and pyramids, whose solidities are readily determined by the ordinary rules for the mensuration of solids." Other methods "consist in taking a number of equidistant profiles, and calculating the solid contents between each pair, either by multiplying the half sum of their areas by the distance between them, or by taking the profile at the middle point between each pair, and multiplying its area by the same length as before." In order to save labor and insure accuracy, tables for these calculations have been prepared and published.

Care must be taken in determining the *lead*, or the average distance to which the cuttings must be transported in making the fillings, a distance usually assumed, in each case, to be the length of the right line joining the centre of gravity of the solid of excavation and that of embankment. The least possible lead is essential from considerations of economy, and this is usually secured when such conditions are interposed that the paths over which the different portions of the solid of excavation are conveyed away to the solid of embankment, shall not cross each other either horizontally or vertically.

These conditions require that the sum of the products, obtained by multiplying all the elementary volumes by the distances over which they are respectively transported, shall be a minimum. As the computations involve the employment of the higher mathematics, they are not inserted here.

Growth of Excavated Earth.

It must be remembered that the different kinds of earth do not fill the same volume in artificial embankments that

they previously occupied in their natural bed. The *growth,* or augmentation in volume, of freshly-dug earth, varies from 15 to 25 per cent among the various kinds, but where formed and compacted into embankments, it settles or shrinks to less than its bulk in the natural bed. This shrinking for different earths, is approximately as follows: gravel or sand about 8 per cent; clay about 10 per cent; loam about 12 per cent; loose vegetable surface soil about 15 per cent; puddled clay about 25 per cent. Mr. John C. Trautwine, C. E., found that 1 cubic yard of hard rock broken into fragments made $1\frac{9}{10}$ cubic yards of loose heap; $1\frac{3}{4}$ cubic yards carelessly piled; $1\frac{6}{10}$ cubic yards carefully piled; $1\frac{1}{2}$ cubic yards of very carelessly scabbled rubble, or $1\frac{1}{4}$ cubic yards of somewhat carefully scabbled rubble.

Moving Earth.

In excavating and removing earth, it is first loosened with picks, spades or plows, and then shoveled into the barrows or carts which convey it away. For short haulages, say of 90 to 100 feet, the ordinary road-scraper holding about $\frac{1}{10}$ of a cubic yard may be advantageously used, when the height to which the earth has to be raised does not necessicate ascents steeper than 1 in 5. For distances exceeding the sphere of scrapers, or where these cannot be advantageously employed, earth is generally conveyed in wheel-barrows. The limiting distance, when one-horse carts should replace barrows, will seldom exceed 250 feet for all the various kinds of earth. This includes loosening, loading, moving, spreading, and the wear and tear of vehicles and tools. It is stated that, upon English works, with barrows holding $\frac{1}{10}$ of a cubic yard, the limit is 300 feet.

Kind of Vehicle.	Length of lead, or distance moved in feet.	Number of cubic yards in place, moved per day by each vehicle.	Pure, stiff Clay, or cemented Gravel.		Light, sandy Soils.		Strong, heavy Soils.	
			Loosened with pick.	Loosened with plow.	Loosened with pick.	Loosened with plow.	Loosened with pick.	Loosened with plow.
			cents.	cents.	cents.	cents.	cents.	cents.
Wheelbarrows.	25	25.7	14.62	10.12	8.79	7.52	11.62	9.12
	50	22.1	15.30	10.80	9.47	8.20	12.30	9.80
	75	19.3	16.02	11.52	10.19	8.92	13.02	10.52
	100	17.1	16.74	12.24	10.91	9.64	13.74	11.24
	150	14.0	18.15	13.65	12.32	11.05	15.15	12.65
	200	11.9	19.52	15.02	13.69	12.42	16.52	14.02
	250	10.3	20.95	16.45	15.12	13.85	17.95	15.45
	300	9.07	22.40	17.90	16.57	15.30	19.40	16.90
	400	7.36	25.20	20.70	19.37	18.10	22.20	19.70
One-horse Carts.	300	28.6	20.98	15.48	13.50	12.23	17.98	15.48
	400	25.0	21.71	17.21	14.23	12.46	18.71	16.21
	500	22.2	22.44	17.94	14.96	13.69	19.44	16.94
	700	18.2	23.88	19.38	16.40	15.13	20.88	18.38
	1000	14.3	26.05	21.55	18.57	17.30	23.05	20.55
	1400	11.1	28.91	24.41	21.43	20.16	25.91	23.41
	2000	8.33	33.31	28.81	25.83	24.56	30.31	27.81
	½ mile	6.58	37.95	33.45	30.47	29.20	34.95	32.45
	3000	5.88	40.51	36.01	33.03	31.76	37.51	35.01
	3500	5.13	44.11	39.61	36.63	35.36	41.11	36.61
	4000	4.54	47.81	43.31	40.33	39.06	44.81	42.31
	1 mile	3.52	57.09	52.59	49.61	48.34	54.09	51.59
	1½ mile	2.40	76.33	71.83	68.85	67.58	73.33	70 83

Beyond a certain distance two-horse wagons should take the place of carts; and where the lead is 1¼ to 1½ miles a temporary railway and a locomotive engine and dirt-cars become desirable. Within the last few years steam excavators, capable of digging and loading 100 cubic yards per hour, at a cost of 2½ to 3 cents per yard, have been used upon some extensive works.

The cost per cubic yard of loosening, loading, transporting to different distances, and spreading soils, including repairs to vehicles and tools, is given in the foregoing table (condensed from Trautwine), based on man's labor at $1.00, horse at 75 cents, and cart at 25 cents per day; one driver to 4 carts.

Completed Map, and Specifications.

Having finally adjusted all questions of gradients, excavations and embankments, and re-examined the ground, the line adopted should be carefully plotted upon the map, together with longitudinal and numerous cross-sections, to show the cuttings and fillings, as well as the natural surface of the ground.

Specifications of the several kinds of work, and working drawings of bridges, culverts, etc., should also be prepared.

Upon the longitudinal section of the road, at points taken at equal intervals apart (say 50, 75 or 100 feet) the vertical distance of the natural surface above or below the road surface should be marked in feet and inches.

In order to indicate the grades, the heights of the same points above an assumed horizontal line called the *datum line,* should also be marked. These points should be numbered on the drawing.

Fixing the Line on the Ground.

The axis of the road is located on the ground by driving stakes to correspond with the several points on the map. These stakes are lettered *cut*, or *fill*, with the number of feet added, to indicate that the natural surface at these points must be *cut down* or *filled up* the specified distance, in order to attain the position of the road surface. Stakes showing the width of the roadway, and the lateral limits of the cuttings and fillings should also be established.

Earthwork is a term applied to the movement and disposal of earth, whether the material handled be common earth or rock.

Side Slopes in Cuttings.

In *excavations*, the inclination which should be given to the side slopes, and the measures, if any, which should be adopted for giving stability to their surfaces, will be governed in a great measure by the inclination and direction of the strata, the kind of soil, the degree of exposure to the action of springs, and the severity of the seasons.

On most soils, such as garden loam, and other mixtures of clay and sand, compact clay, and compact stony or gravelly soils, the slopes should be about two base to one (or at most one and a half,) perpendicular. In some cases an angle of 45°, or 1 on 1, will answer.

It is always desirable that the roadway should be exposed as fully as possible to the action of the wind and sun, in order to facilitate the evaporation of moisture from its surface. Hence, the deeper the excavation, the more gentle should be the side slopes, particularly those on the south side in high northern latitudes. When the slopes are

exposed to no other causes of destruction than the action of the elements—to wind, rain, and frost—it is not essential that any special precautions should be adopted for their protection, although the expense of maintenance will be considerably lessened by sodding them, or by first covering them with three or four inches of rich soil and then seeding them down, or setting them with plants of some suitable variety of grass.

If the soil be infested with springs that might destroy the stability of the slopes, and wash them down into the roadway, they should if practicable be tapped near their source by digging into the side of the slope, and the water conveyed by blind drains or otherwise into the side drains. After the drain is constructed the earth is filled in over it, and the slope restored to the required shape. Figs. 7, 8 and 9 show cross sections of three forms of drains,

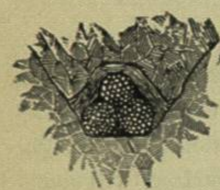
FIG. 7.

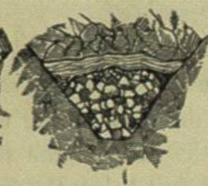
FIG. 8.

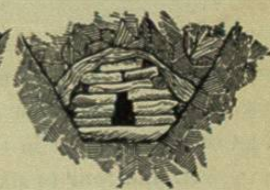
FIG. 9.

either of which will answer for this purpose, in ordinary cases. Fig. 7 is constructed with three fascines, laid longitudinally in the trench excavated to the source of the spring. A single fascine of equivalent area in cross-section, or loose brushwood placed compactly in the trench, may be substituted. Fig. 8 shows a blind drain of fragments of stone or loose rubble. In Fig. 9 a clear water way is left in the middle of the drain. In either case the sides and top of the drain should be covered with straw, coarse grass, small brushwood, or sods with the grass side next the drain, to prevent the latter becoming choked with earth.

In cases where the entire body of the slope is saturated with water, and the sources of the springs are unknown, or cannot be reached, good drainage may generally be secured by a series of blind drains extending a few feet into the slope at its base, or by a single drain constructed of loose stone in the form of an inclined retaining wall, parallel with the foot of the slope, as shown in Fig. 10. Similar

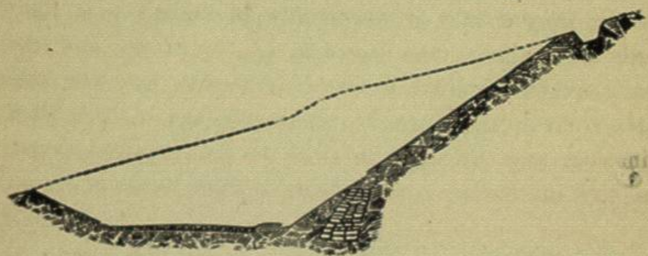

FIG. 10.

precautions to those already mentioned must be taken in this case to prevent the drain becoming choked. A series of parallel tile drains in the body of the slope, six to eight feet apart, and four to six feet below the surface, will sometimes secure good drainage in springy soils. The round tiles are the best, and the diameter of the bore need not exceed one to two inches. They are laid end to end in a narrow trench, then covered with straw, hay, or turf to prevent their choking, and the trench filled up. These drains should have an inclination of one in eighty to one in one hundred, and may all empty into a masonry conduit or earthen pipe leading down the slope into the side drains of the roadway. Instances may occur where a deep narrow trench dug just beyond the crest of the side slope, and filled

up with broken stone or pebbles, will cut off all the springs. As such an arrangement will also prevent the surface water from higher levels from running over the slope, it may be the least costly method of effecting good drainage. Deep shafts for collecting the water are sometimes sunk from the natural surface above the crest of the slope, and the water conveyed from them into the side drains of the roadway, through pipes or drains laid by tunneling. In deep cuttings in clayey soils, of such character that water will render them sufficiently plastic to slide down the slope, or soils easily cut into gullies by running water, it is well to form the slope in benches or *berms*, shaped into shallow drains called catchwater drains, to receive the water and earth from the higher levels. They should have a slight inclination longitudinally, so as to discharge their water at the foot of the slope, or, at suitable intervals, into paved open drains running directly down the face of the slope.

In soils formed in great part of unctuous clay, or alternate layers of clay and sand, there is always a tendency to *slides* during the wet season, or during the spring in high latitudes, when the frost is leaving the ground. Under these circumstances special precautions should be taken for the protection of the side slopes, such as (1) cutting off all springs if any exist, (2) turning off the water from the higher levels by a drain above the crest of the slope, and (3) arrangements for conveying off the water which falls upon the slopes, either by carefully constructed catchwater drains, by sodding the slope, or by a combination of the two. Before top-dressing the slope with rich soil, preparatory to sodding or seeding down, it should be cut into horizontal benches or steps to guard against slides, as shown on the right in Fig. 10. This method may be advantageously applied to those kinds of slaty rocks which disintegrate rapidly by alternate freezing and thawing. (The benches are incorrectly represented on the left hand slope in the figure.)

Although the sides of a cutting through compact rock would stand firmly, if left in a vertical position, it is desirable that they should be sloped to some extent so as to expose the road-surface to the drying influences of the wind and sun. Unless prevented by considerations of economy, the slope on the side next the equator in high latitudes, should be as great as one base to one perpendicular, while one base to twc perpendiculars will ordinarily answer on the opposite side.

When the depth of the excavation exceeds a certain limit, generally assumed to be about 60 feet, it is in most cases cheaper to tunnel than to make a cut. It is however, seldom necessary to resort to this expedient, in constructing common roads, for which indeed it is peculiarly inappropriate, on account of excluding the wind and sun.

Embankments.

Embankments should be made sufficiently firm and compact to resist all tendency to unequal settlement and slides. They should therefore possess not only great but *uniform* solidity, especially if they are high, conditions which are best secured by forming them in successive horizontal layers well compacted by ramming. As this method is expensive, it is usual, from considerations of economy, to carry out an embankment to its full height from the beginning, at the same time making the cut, which supplies the earth, to its full depth. The earth, on being tipped at the end of the bank undergoing formation, slides down the slope and finally comes to temporary rest, approximately at the angle of repose. (See Fig. 11).

As the rapidity with which this kind of work can be executed depends upon the number of "tipping places"

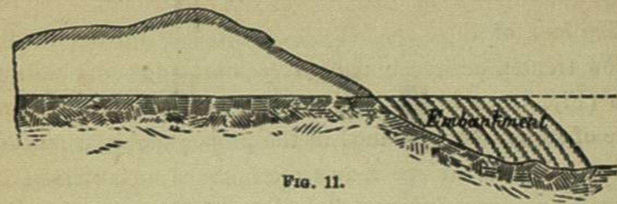

Fig. 11.

afforded by the width of the embankment, it is usual to form the latter at first broader at the top, and correspondingly narrower at the bottom than the required dimensions, maintaining of course the requisite area of cross-section. The excess at the top (the angles at A and C, Fig. 12) is after-

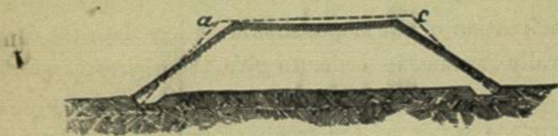

Fig. 12.

wards moved down to the bottom, thus securing the required width of base, and inclination of side slopes.

The sides of the embankment should always be kept somewhat higher than the centre line, in order to retain the rain fall, and consequently hasten the consolidation of the mass. For the same reason when the case will warrant the expense of constructing in successive horizontal layers they

Fig. 13.

should be made concave on the top, as shown in Fig. 13 This will also lessen the danger of slides.

Embankment Slopes.

The foot of the slope may be secured by resting it in a shallow trench, or by abutting it against a low dry wall of stone (Fig. 13), and, in localities where there is an abundance of stone to be obtained in the proper shape at moderate cost, the entire slope may sometimes be advantageously replaced by a sustaining wall laid up without mortar. In cases where the embankments require more earth than the necessary excavations afford, a sustaining wall may be cheaper even in its first cost, than a slope of earth, while the current cost of its maintenance will be small in comparison with that of earthwork.

The inclination of the slopes should be less than the earth will naturally assume, in order to give them greater stability, and they should be protected by sodding or seeding down.

The surface water of the top may be collected by side-drains and carried down the slopes at intervals either in paved gutters or blind drains. If allowed to shed itself over the slope, gullies would be formed, and the embankment eventually destroyed.

When extensive excavations have to be made through rock, and stone for embankment purposes is therefore plenty and cheap, the entire face of the slope may be roughly paved or covered with stone, at moderate cost, rendering all other precautions for its preservation unnecessary. Fragments of various sizes and shapes, from one to two feet in length, may be used for this purpose. They should be placed generally with the longest edges down, their faces at right angles to the slope and parallel with the axis of the road. It is not usual to protect the slopes of embankments in this careful

manner, but they should never be required to carry off the surface water of the roadway.

Hill-Side Roads.

A roadway located upon a hill-side is usually formed half in excavation, and half in embankment, allowance being made for the shrinkage of the latter. To guard against slides, the natural surface should be prepared to receive the embankment, by cutting it into benches as in Fig. 14. The

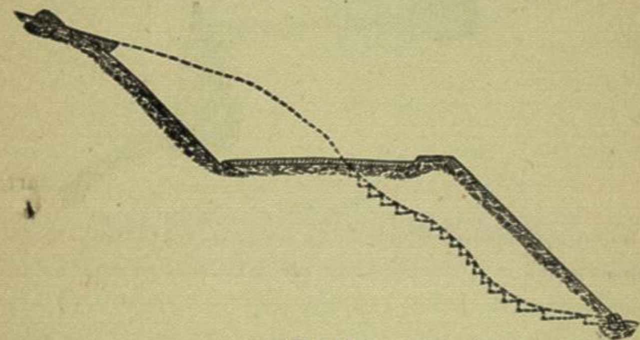

FIG. 14.

foot of the slope should abut against a low dry stone wall below the reach of frost. At the crest of the slope in excavation, an open trench should be formed to intercept and convey away the surface water from the higher ground.

Upon steep hill-sides, the side slopes of excavation and of embankment must both be replaced by sustaining walls. Dry walls will usually answer for these purposes, if the stone can be procured of suitable sizes. (Fig. 15.)

If the hill-side upon which the road is located be a rocky ledge of less inclination than one perpendicular to one base, the same method of construction by making the excavations supply the embankments may be followed. The enrockment *filling* in this case will occupy a greater volume than the cutting from which it is taken.

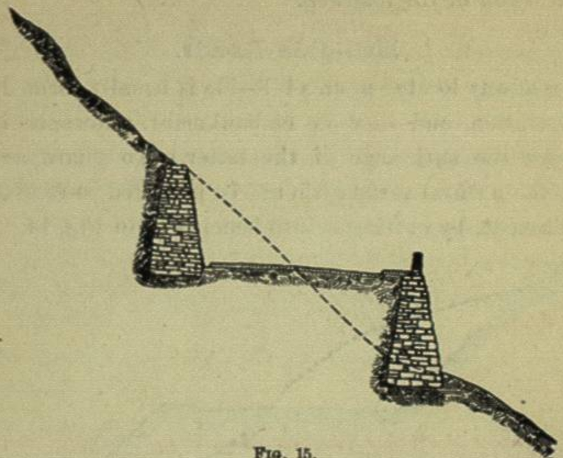

FIG. 15.

When the natural slope of the ledge is very steep, as for example when it is steeper than one base to one and a half perpendicular, the whole roadway may be formed in excavation, or, as shown in Fig. 16, by cutting the face of the ledge into two or more horizontal steps with vertical faces, and building up the embankment in the form of a solid stone wall, in horizontal courses, either with or without mortar. In the figure the lower step, on which the wall rests, may sometimes be advantageously replaced by two smaller steps, *a, c*, and *b, b*. On account of the great comparative cost of excavations in rock, estimates for work of this character should always be based upon numerous and careful sections. All attempts to lessen the quantity of excavation by increasing the number and diminishing the width of the steps, require additional precautions against settlement in the built-up portion of the roadway.

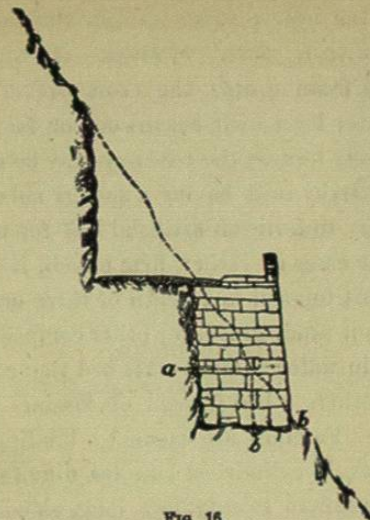

FIG. 16.

Roads over Marshes and Swamps.

If the road runs through a swamp or marsh resting upon a firm substratum, the soft material should be removed when its depth does not exceed two or three feet, and the road embankment formed directly upon the hard soil. A wide and deep open ditch should be cut in the marsh on each side of the road, to receive the surface drainage and cut off the water from the adjacent marsh.

Roads over deep marshes must be constructed upon a different plan. A system of thorough deep drainage being essential, the method usually followed is to cut a deep and wide ditch on each side, leaving between each ditch and the road covering an unoccupied strip or berm several feet in width. Cross drains should connect the two main drains at frequent intervals, to drain the soil under the roadway. These cross drains are formed by digging trenches a little deeper than the lowest water level in the side ditches, and filling them with fragments of stone. If water permanently stands in the main drains, the cross drains may be filled below the water level with brushwood or fascines. On the foundation thus formed the roadway may be constructed.

In deep marshy soils having a spongy subsoil, it is sometimes necessary to form an artificial bed for the road covering. In some cases of rather firm marsh, it is sufficient to remove the soft top-soil to a depth of three or four feet, and substitute for it sand, gravel, or other compact material that will not retain water. Upon this bed the road covering is placed. In others a bed formed of fascines has been used with success. Fascines are made by binding together, by wires or withes, in cylindrical bundles nine to ten inches in diameter and ten to twenty feet long, slender branches of underwood. A layer of fascines, placed across the road, side by side, is first laid down. A second layer at right angles to these follows, and if necessary a third transverse layer, and so on until the required height of road bed is attained. Stout stakes or pickets are driven through the entire thickness of fascines to keep them firmly in place, or, the withes may be cut after each layer is in position, so as to allow the brushwood to assume the form of a layer of uniform compactness. The top layer should be placed transversely to the line of the road. Having prepared the foundation in this manner the road covering is placed upon it in the usual way. If deemed necessary, cross blind-drains leading to the side ditches, may be introduced under the bed of fascines in order to secure deeper sub-drainage.

Roads over Tidal Marshes.

Roads constructed over marshes which are subject to

daily overflow from the tides, may be effectively drained, down to the level of ordinary low water, by a very simple system of sluice-gates. The ordinary case is where the road crosses a tidal stream and then traverses the marsh bordering thereon. Under such circumstances, the earth excavated in cutting the two parallel side ditches, should be formed into a dike or levee on the outer side of each ditch and high enough to exclude high water. The ends of these dikes should be connected, along the margin of the stream where the road joins the bridge, by a dike of the same height, thus surrounding the roadway and side ditches with a continuous impervious bank of earth, rising above high water level.

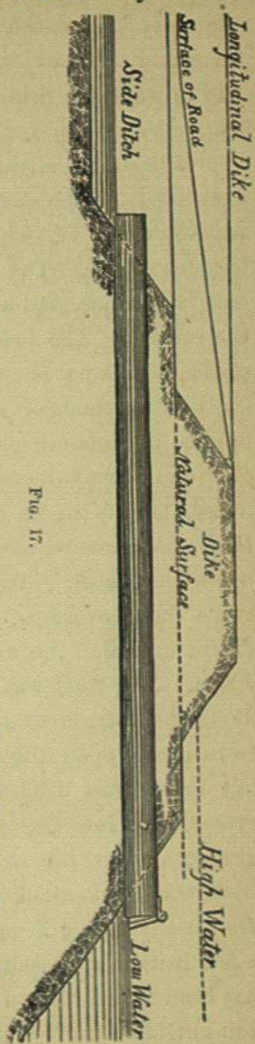

Fig. 17.

Pipes of wood or iron, provided with valves on the outer end opening outward, are then inserted, at the level of low tide, through the dike which separates the ends of the side ditches from the tidal stream. The water flows out through these pipes whenever the tide level outside is below the water level in the ditches. When the reverse ensues the gates are closed by the external pressure of the water, and all inward flow prevented. Hence the water in the ditches remains at the level of low tide, and the surface of the road should be established at such height above that level that it will always be firm and solid. Whatever level may be adopted for the roadway across the marsh, it must on approaching the stream rise to the top of the dike to prevent overflow from the stream at that point. This point is illustrated in Fig. 17, which is a longitudinal section through the sluice-pipe. The road is built a little higher than the natural surface, and ascends to the crest of the dike, near the stream. The bridge across the stream in continuation of the road is not shown.

This method of drainage has been very successfully applied in reclaiming the "Jersey Flats" between the cities of Newark and Jersey City, New Jersey, a large tract of marsh land with its natural surface not higher than the level of ordinary high tide, and in large part some inches below that level. These Flats were formerly subject to twice daily overflow, from the Passaic and Hackensack rivers, in which the mean rise and fall of the tide is about 4 feet. The tract was surrounded by a dike or levee formed along the margin of the stream, of the material excavated from a wide open ditch parallel to it on the inside. Numerous broad cross ditches, dividing the marsh into parallelograms, lead into this main ditch. The sluices are located at suitable intervals so as to drain from the main ditch into both the Hackensack and the Passaic rivers. The pipes are usually placed in pairs, and are of various sizes, in only a few instances exceeding two feet in interior diameter. It has been found that a difference of one inch in the inside and outside water level, will open or close the sluice-gates.

By this means a noxious swamp has been converted into arable and thrifty land. It is sufficiently firm to support a roadway upon its surface, without any special precautions in preparing the road bed.

When the embankment requires more earth than the excavation can supply, the deficiency is made up from *side-cuttings,* made in some convenient locality near by. On the other hand when the embankments do not consume all the earth furnished by the excavations, the excess is deposited in *spoil-banks,* usually located on a somewhat lower level than the road surface, care being taken to provide for the drainage in such a manner as to prevent the formation of pools of water that might affect the stability of the side slopes of the excavations.

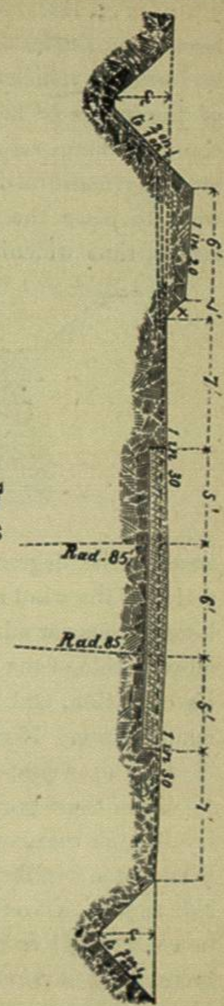

FIG. 18.

Side Drains.

It is essential to the proper condition of a road, that the surface water of the soil adjacent thereto shall be cut off by suitable open side drains, so that it can not filter under the roadway, and render the subsoil soft, spongy, and incapable of sustaining the weight upon it. Otherwise the road covering would sink into the soft earth beneath, and require to