PRACTICAL TREATISE

ON

ROADS, STREETS, AND PAVEMENTS.

CHAPTER I.

LOCATION AND GRADES OF COUNTRY ROADS.

Considerations Governing Location.

THE considerations which should govern the Engineer in locating the line of an ordinary wagon road are (1) the present and prospective amount of traffic over the road; (2) its general character, whether light or heavy; (3) the convenience and necessities of the community tributary to the line; and (4) the natural features of the country through which the road must pass. The labor of the preliminary examination of the ground will be considerably lessened by keeping in view a few elementary principles, viz: (1) that the natural water courses are not only the lowest lines, but the lines of the greatest longitudinal slope in the valleys through which they flow; (2) that the direction and position of the principal streams give also the direction and approximate position of the high ground or ridges which lie between them; and (3) that the positions of the tributaries to the larger streams generally indicate the points of greatest depression in the summits of the ridges, and therefore the points at which lateral communication across the high ground separating contiguous valleys could be most readily made.

Reconnaissance.

With the aid of an ordinary map of the country, if reasonably correct, it is entirely practicable to trace upon it with a sufficient degree of accuracy for the immediate object in view, not only the general directions of the ridges or highest ground, but also to locate approximately those routes most suitable for the purposes of a road across the hills, from one valley to another.

Being provided with the information usually supplied by maps or, in the absence of trustworthy maps, having secured that information by an instrumental examination, the topographical and other characteristic features of the ground should be carefully studied by travelling in both directions over the several routes, upon any one of which the line may be located, carefully noting down for future comparison, the distinctive features of each.

Aneroid Barometer.

If the line passes over such hilly or undulating ground, that considerable differences of level are necessarily encountered in its location, valuable aid may be derived from a pocket Aneroid barometer. This instrument shown in section through the axis in Fig. 1, consists of a flat cylindrical box A, exhausted of air, the top of which is thin metal corrugated in concentric circles so as to render it quite elastic. As the atmospheric pressure increases, the elastic top of the box is forced in or down, and as it decreases it is forced out or up. This movement of the top of the box due to changes

in the atmospheric pressure, is conveyed by multiplying levers DE, EG, GH, and a small chain II to an index needle NN, moving over a circular scale MM, graduated to correspond with the standard mercurial barometer. The spiral spring S, by its tension raises the long arm of the lever DE, when the pressure on the top of the box is lessened, thus keeping the short arm of the lever constantly in contact with the fulcrum C. The Aneroid is used by the following rule: The sum of the readings at two stations, is to their difference, as 55,000 (or twice the height of the atmosphere in feet), is to the ele-

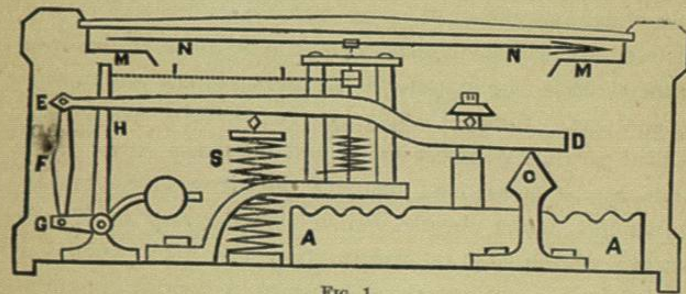


FIG. 1.

vation required. Thus, if the reading at the foot of a hill is 30.05, and at the top 29.44, we have the following 59.49 . 0.61 : : 55,000ft. : 564ft.

By the intelligent use of this barometer, the scope of inquiry may frequently be much narrowed at the outset, and the labor and expense of the subsequent survey greatly abridged. For instance, if the line of communication is to connect two valleys by crossing the high ground between them, it should be located, other things being equal, in the lowest depression of the summit. A reconnaissance with a barometer should indicate with an error not exceeding 10 to 15ft. the relative altitude of the several summit depressions, and therefore the best location of the route, so far as the question of grade fixes the location. The average of several observations with the barometer, is desirable.

Surveys, Map and Descriptive Memoir.

The reconnaissance having been completed, and the inquiry narrowed down by the exclusion of the least practicable routes, preliminary surveys should then be made of the several *trial-lines*, with a view to determine their length, direction, and position, together with a longitudinal section and numerous cross-sections of each line. All this should be done with sufficient accuracy and minuteness of detail to form the basis of comparative estimates of their practicability and cost. Money liberally spent in surveys entrusted to skillful persons, is wisely spent, and offers the surest guarantee against subsequent mistakes and errors of judgment. Its amount, at the outside, cannot exceed a very small percentage of the cost of constructing the road, while the results, judiciously employed, are sure to furnish innumerable suggestions for lessening the cost without impairing the excellence of the communication.

Map.

The data obtained from the surveys should be carefully embodied in a map, showing with considerable detail, the topography of the country embraced by the several *trial-lines*, the exact position of these lines, and all the longitudinal and cross-sections. The horizontal scale of the sections should be the same as that of the map, while the vertical scale should be considerably larger, in order to show clearly all the inequalities of the ground. With a horizontal scale

of 500ft. to the inch, the vertical scale may be only 20ft. to the inch.

Descriptive Memoir.

The descriptive memoir should give with minuteness all information, such as the nature of the soil, the character of the several cuttings, whether earth or rock, the kind of rock, etc., etc., that cannot be set forth on the map. The importance of carefully noting in the memoir, and as far as practicable upon the map also, all variations of the character of the cuttings through rock, and especially of maintaining a strict distinction between cuttings in rock and cuttings in earth, will be admitted, when it is remembered that excavations in earth can be made at less than one-fourth the cost of excavations in rock.

Location of the Line.

"In selecting among the different lines of the survey the one most suitable for a common road, the engineer is less restricted, from the nature of the conveyance used, than in any other kind of communication. The main points to which he should confine his attention are, (1) to connect the points of arrival and departure by the shortest or most direct line · (2) to avoid all unnecessary ascents and descents, or in other words to keep the ascents and descents within the smallest practicable limits ; (3) to adopt such slopes or gradients for the centre line of the road as the kind of conveyance used may require ; (4) to give the centre line such a position with reference to the natural surface of the ground, and the various obstacles to be overcome, that the cost of labor for excavations and embankments required by the gradients adopted, and also the cost of bridges and other accessories, shall be reduced to the smallest amount." (Prof. Mahan.)

Except in a flat and level country, it will seldom be practicable to adopt, for the axis of the road, the shortest line between the points of arrival and departure. Departures from a straight line are determined by a variety of considerations. In crossing a dividing ridge between two valleys, we seek a depression in the summit, in order to avoid expensive cutting, or the alternative of steep or impracticable gradients; in descending a valley longitudinally, we keep well up on the side of the hill, if necessary, to avoid bridging the ravines and secondary water-courses; if we encounter a swamp or shallow pond, we can frequently, by turning to the right or left, entirely omit the construction of an expensive causeway or other road bed, or substitute for it a short bridge over a narrow water-course, with easy approaches on either side; a stream may cross and then re-cross the direct line, forming an elbow which may sometimes be turned without greatly augmenting the length of the road, thus avoiding the construction and maintenance of two bridges; we may turn aside and even bridge a stream in order to get upon that slope of a valley which will give the best exposure of the road surface to sun and wind; or we may lengthen the road for the purpose of procuring better material for its construction.

Questions of Expediency to be Considered.

Not infrequently other questions not strictly within the province of the engineer claim attention to such degree that although a straight line between the two termini of the road may be the best, considerations of expediency will very properly prevent its adoption. Intermediate communities and towns contiguous to the line may require accommodation,

and whether such accommodation shall be afforded by lateral branch roads, leaving the main line essentially straight, or by running the latter through the several centres of business, will have to be determined upon principles more or less independent of the bare problem of construction and maintenance. For example take the simplest case of three towns A, B, C, Fig. 2, situated upon a uniformly level plain, where the cost of constructing and maintaining a line of communication will be directly proportional to its length.

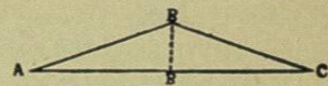


Fig. 2.

Suppose the points of arrival and departure, A and C, to be 120 miles apart, and that B is equi-distant from A and C, but located 20 miles off the direct line AC. If each town sends out 20 tons of freight per day to be distributed equally (10 tons to each) between the other two towns, a simple calculation will show that with a straight road AC, between the extreme points and a perpendicular branch road B′B to the intermediate town, the daily transportation of this 30 tons of freight, will be equivalent to transporting 1 ton 5600 miles, while if one straight road be built from A to B, and another from B to C, the total carriage will be equivalent to conveying 1 ton only 5060 miles. The difference, (equal to 540 tons carried 1 mile) in favor of the lines AB, BC, over the lines AC and B′B is borne unequally by the three towns in proportion of 335 tons to B, and $102\frac{1}{2}$ each to A and C. In the case stated, it is for the mutual advantage of all the three communities to locate the line from A to B and from B to C. But the conditions would be different if the great bulk of the traffic is between the towns of A and C. For example, if those towns exchange 20 tons per day with each other, and only 2 to 3 tons per day with the town B, then the total mileage of transportation necessary in making the interchange, setting other considerations aside, would favor the construction of a straight line AC, between the terminal towns, and a perpendicular branch line B'B to the intermediate town. But as this would require a greater length of road by 13½ miles (140—126½) than a continuous line A B C passing through the intermediate town, the expediency of building and maintaining upwards of 10 per cent more road than is absolutely necessary to connect the three towns, presents itself as a question of some commercial importance, and before adopting the longer system, it should be made quite clear that the yearly saving in cost of transportation will be more than sufficient to pay the interest on the first cost of constructing 13½ miles of road, as well as the annual expense of its maintenance. Except in extreme cases where the two towns at the ends of the line are large in comparison with the intermediate towns, it will usually be found to be most conducive to the convenience of the general public to run the line through all the principal communities, in preference to the plan of communicating with the intermediate places by branch roads, which might necessitate branch lines of wagons and coaches, connecting with those of the main line, attended by all the usual inconvenience and expense of transferring passengers and goods at the points of junction.

In the general case, however, the road will not traverse a level plain but will cross hills, ravines, rivers; and other accidents of the ground, so that the proper solution of the problem will involve a variety of considerations, among which the engineer's ideal of a straight and level line, the

wants of the communities to be accommodated, and economy in cost of construction will generally be more or less at variance.

As it should be the first business of the engineer to make himself thoroughly familiar with the character of the country adjacent to the line, for some distance on either side, all the preliminary field work should be directed to that end.

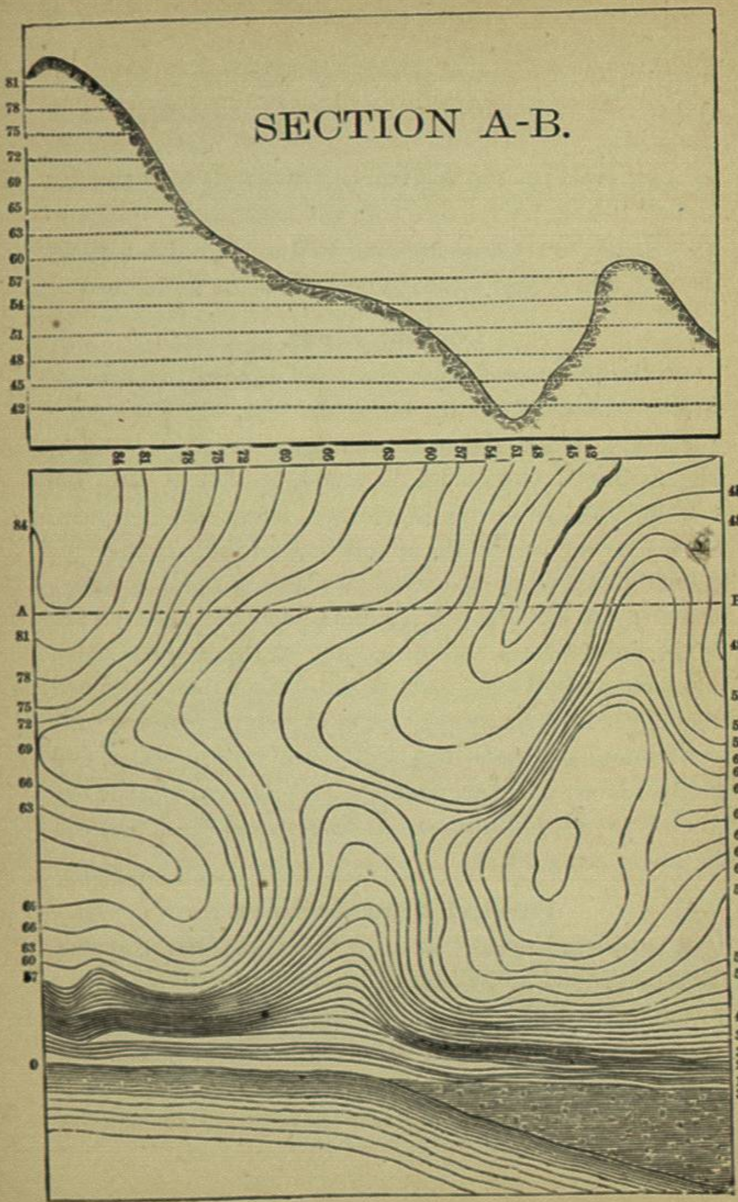
Contour Lines.

In laying out important roads, and especially in locating streets in towns or thickly settled districts, where the questions of gradient, drainage, sewerage, and water supply assume special importance, it would be well to place the contour lines, or curves of uniform level, upon the map. These curves represent the intersections of the surface of the ground with a series of horizontal planes at equal distances apart, of say 3ft. 5ft. 10ft. or more—and indicate at once to the practiced eye the topography of the country which they embrace. We give, Fig. 3, the contour lines of a small tract of country, showing a variety of natural features, such as undulating slopes, steep hill sides, ravines, water, and marsh. Every curve represents a level line traced upon the ground, the vertical distance, or difference of level, between the curves being 3 feet.

Parallel Cross Sections.

A survey so complete as would be required for mapping the contour lines in the manner shown in Fig. 3, is seldom, if ever, resorted to, and is indeed unnecessary for the proper location of a country road. It will suffice to take a series of cross sections parallel to each other, and extending a sufficient distance laterally to embrace the width of the country

Fig. 3.



under examination. By plotting these sections to a scale, in their true relative positions, all referred to the same level or datum line, it will be easy to locate the axis of the road properly thereon, and to estimate the quantities of excavation and embankment, provided the sections are taken sufficiently near together. Their distances apart should of course be less in proportion to the ruggedness and unevenness of the country. Suppose, for example, that C, D, M, N, Fig. 4, represents a portion of the strip of country under examina

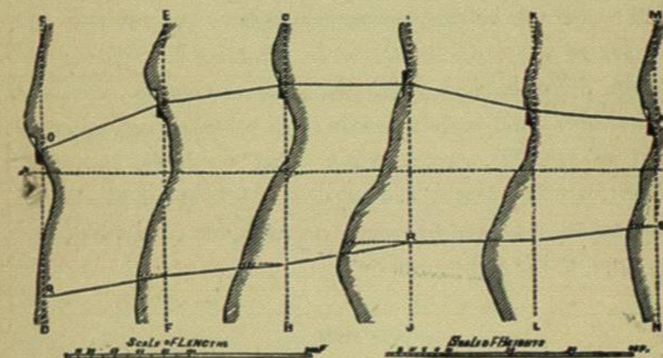


Fig. 4.

tion and A, B, the general direction of the road, which must be located somewhere between the lines C, M, and D, N. Having run the several lines of levels C, D, E, F, etc., transversely, and at least one line A, B, longitudinally so as to establish a common datum line for all, the sections are drawn as shown in the figure. As a part of the map or plan the right lines C, D, E, F, etc., show the positions of the cross sections, while they are also the datum lines, all on the same level, of their respective sections. Those portions of each section to the left of the datum line represent ground above that line and those portions to the right, below it, and a line like O, P, drawn through points in the several sections that are at the same distance from and on the same side of the datum lines, will show the exact location of a level line traced on the surface of the ground. Hence the axis of the road if located on the line O, P, will be level, while upon the line Q, S, it would have an ascending grade of $\frac{1}{30}$ from Q, to R, and a descending grade of $\frac{1}{30}$ from R to S.

Having completed the surveys, and prepared the map and memoir with as much detail as possible, the engineer will then be able to study with intelligence the relative advantages of the trial lines, and to establish definitely their location, direction and gradients, in order that the volumes of excavations and embankments shall balance each other as nearly as possible, except when other methods, hereafter referred to would lessen the expense, while the cost of constructing the necessary bridges, culverts, etc., shall be carefully kept at the minimum.

Grades.

Upon common roads the grades, or the angles which the axis of the road should make with a horizontal line, depend so much upon the kind of vehicle employed for traffic, the character of road-covering adopted for the surface, and the condition in which that surface is maintained, that no empyrical rule can be laid down. The grade should not be so great as to require the application of brakes to the wheels in descending, or to prevent ordinary vehicles carrying passengers ascending at a trot. In general the gradient should be somewhat less than the *angle of repose*, or that angle upon which the vehicle in a state of rest would not be set in motion by its own weight, but would descend with

slow uniform velocity if very slight motion be imparted to it. The grades therefore, suitable for any road, will depend upon the condition, with respect to smoothness and hardness, in which the surface is to be maintained, and hence upon the kind of road-covering used; and as the force of gravity is the same whether the road be rough and soft, or smooth and hard, steep grades are more objectionable upon good roads than upon bad.

Tractive Force.

Many ingenious experiments have been made at various times to ascertain, in functions of the quality and condition of the road surfaces, the measure of the *tractive force*, or the force required to overcome the resistances which oppose themselves to the movement of a vehicle along horizontal roads of different degrees of smoothness and hardness, and covered with different materials. From some of the experiments of M. Morin, conducted for the French government, the following general results were deduced:

1. The force of traction varies directly with the load and inversely with the diameter of the wheels.

2. The resistance is practically independent of the width of tire on paved or hard Macadamized roads, where that width exceeds 3 or 4 inches.

3. At ordinary walking speed the traction is the same for carriages with springs, as for those without them, the other conditions being the same.

4. The force of traction increases with the speed upon paved, or hard Macadamized roads. When the speed exceeds 2½ miles per hour the increase in the resistance varies directly with the increase in velocity.

Some of M. Morin's results are tabulated below.

Kind of Road.	Relation of Force of Draught to Weight of Vehicle and Load.					
	Carts.	Trucks of two tons.	Diligences of five tons.		Carriages with seats hung on springs.	
New road, with gravel covering, 5 inches thick....	$\frac{1}{12}$	$\frac{1}{9}$	$\frac{1}{8}$		$\frac{1}{8}$	
Solid earth causeway, with gravel covering 1½ inch thick..................	$\frac{1}{16}$	$\frac{1}{11}$	$\frac{1}{10}$		$\frac{1}{10}$	
Earth causeway in very good condition	$\frac{1}{41}$	$\frac{1}{29}$	$\frac{1}{26}$		$\frac{1}{26}$	
			Walk.	Trot.	Walk.	Trot.
Broken stone road, very dry and smooth..	$\frac{1}{75}$	$\frac{1}{54}$	$\frac{1}{48}$	$\frac{1}{41}$	$\frac{1}{49}$	$\frac{1}{42}$
Do. moist and dusty...	$\frac{1}{63}$	$\frac{1}{38}$	$\frac{1}{34}$	$\frac{1}{27}$	$\frac{1}{34}$	$\frac{1}{27}$
Do. with ruts and mud,	$\frac{1}{33}$	$\frac{1}{24}$	$\frac{1}{21}$	$\frac{1}{18}$	$\frac{1}{22}$	$\frac{1}{19}$
Do. with deep ruts and thick mud......	$\frac{1}{19}$	$\frac{1}{14}$	$\frac{1}{12}$	$\frac{1}{10}$	$\frac{1}{12}$	$\frac{1}{10}$
Pavement. Dry	$\frac{1}{90}$	$\frac{1}{65}$	$\frac{1}{57}$	$\frac{1}{38}$	$\frac{1}{59}$	$\frac{1}{39}$
Pavement. Muddy.......	$\frac{1}{69}$	$\frac{1}{50}$	$\frac{1}{44}$	$\frac{1}{33}$	$\frac{1}{45}$	$\frac{1}{34}$

The smootner the road and the less rigid the vehicle, the less will be each equal increase of resistance due to each equal increase of speed.

5. The traction is practically independent of the velocity upon soft dirt and sand roads, or roads freshly and thickly covered with gravel.

6. Upon a smooth-cut, evenly-laid stone pavement, the resistance at a walking speed does not exceed three-fourths that upon the best Macadamized road at the same speed, but at trotting speed it is equal to it.

7. The wear and tear of the road is greater as the diameters of the wheels are less, and is less from vehicles with springs than from those without them.

The following table, resulting from trials made with a dynamometer attached to a wagon moving at a slow pace upon a level, gives the force of traction in pounds upon several kinds of road-surfaces, in a fair condition; the weight of wagon and load being one ton of 2,240 pounds.

1. On best stone trackways..........................	12½ pounds.
2. A good plank road..............................	32 to 50 pounds.
3. A cubical block pavement......................	32 to 33 "
4. A Macadamized road of small broken stones....	65 pounds.
5. A Telford road, made with six inches of broken stone of great hardness, laid on a foundation of large stones set as a pavement...........	46 pounds.
6. A road covered with six inches of broken stone laid on concrete foundation.................	46 "
7. A road made with a thick coating of gravel laid on earth..................................	140 to 147 pounds
8. A common earth road..........................	200 pounds.

In order to apply these results in establishing suitable grades, take the case of the Macadamized road No. 4, in which the tractive force to the gross ton is 65 pounds upon a level road. Let W = the weight of the vehicle and load in pounds; **p** = pressure normal to the road-surface in pounds; **t** = force of traction in pounds on a level road. At the angle of repose of an inclined road, the force, acting parallel to the line of grade, necessary to sustain a carriage and its load in its position on the incline, or to prevent it from moving back by its own weight, is equal to the traction force **t**, which would just move the carriage and load on a level road. Let **h** be the perpendicular and **b** the base of a right angle triangle, of which the hypothenuse B C (Fig. 5) represents the slope of the angle of repose, which somewhat exceeds the greatest admissible gradient. For simplicity, the load may be supposed to rest on a single wheel, shown in the figure. In the smaller similar triangle **t** is the perpendicular,

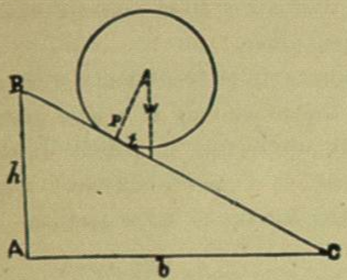


Fig. 5.

p the base, and W the hypothenuse, in which $\mathbf{p}=\sqrt{W^2-t^2}$. From the two similar triangles $\mathbf{t}:\mathbf{p}::\mathbf{h}:\mathbf{b}$, or $\frac{t}{p}=\frac{h}{b}$, and by substitution $\frac{t}{\sqrt{W^2-t^2}}=\frac{h}{b}$. But $\frac{h}{b}$, being the perpendicular divided by the base, represents the angle at the base, or the angle of repose, and this is the maximum admissible gradient. Hence the gradient should not exceed the quotient obtained by dividing the force of traction by the square root of the difference between the square of the load and the square of the traction. Upon good roads **t** is so very small in proportion to W that it may be omitted in the denominator, and we have practically for the angle of repose $\frac{t}{W}$, or the force of traction divided by the weight of vehicle and load.

For road No. 4 the formula becomes $\frac{65}{\sqrt{2240^2-65^2}}, = \frac{1}{34}$

nearly, indicating that for roads upon which the force of traction per ton is 65 pounds, the grade should be not greater than 1 perpendicular to 34 base; and generally the proper grade for any kind of road, or the ratio of the vertical to the horizontal line, will be equal to the ratio between the force necessary to draw the load and the load itself, upon the same road when level. The grade is usually expressed in the form of a vulgar fraction, having 1 for the numerator, and the horizontal distance corresponding to a rise of one foot for the denominator.

In practice the steepest grades that can be allowed upon Macadamized or Telford roads, in the condition in which their road surface is usually maintained, is about $\frac{1}{20}$, it having been determined by experience that a horse can draw up this slope, unless it be a very long one, his ordinary load for a level road, without the help of a second animal; also that he can attain at a walk, a given height, upon a gradient of $\frac{1}{20}$ without more apparent fatigue, and in nearly the same time that he would require to reach the same height over a proportionately longer road with a slope so gentle—say $\frac{1}{34}$—that he could ascend it at a trot.

It is however more desirable, especially for passenger traffic, to keep the gradients as low as $\frac{1}{34}$, or at the greatest $\frac{1}{30}$, as the maximum slope, whether considered as an *ascent* or a *descent*, so that in the former case the speed need not be slower than a trot, while in the latter it will not be necessary to apply a brake to prevent the load pressing forward upon the horses.

Undulating Grades.

It is claimed, as having been demonstrated by experience, that a road constructed on a dead level, or with a uni form slope between points upon different levels—especially if the slope be a long one—is somewhat more fatiguing upon the draft of the horse or mule, than one with an alternation of gentle ascents and descents, of say $\frac{1}{110}$ to $\frac{1}{100}$, and that a horse can draw as heavy a load at as great a speed *up* these gradients, if they are of moderate length, as he can upon a perfect level, while in going *down* he would experience a measure of relief, hardly perceptible perhaps at the time, but which during several days of continual labor would amount to a positive benefit. This idea, although it has the appearance of great plausibility, is probably a mere popular error, unable to withstand the test of intelligent investigation. Upon a very long and steep gradient—one for instance greatly exceeding the angle of repose, and therefore inadmissible upon good roads—it would doubtless be an advantage to have short sections upon which the slope would be less than that angle, where halts could be made for rest, and the animals be entirely relieved of pressure in either direction; but, upon a well devised road, no engineer would be justified in making special provisions for securing a succession of gentle ascents and descents, upon any considerations connected solely with the question of traction.

The proper drainage of a road requires that its side ditches should have a gentle inclination longitudinally, and, in order that the road surface may be kept free from standing water without giving it too great a rise in the middle, suitable longitudinal slopes should be given to it. For this slope English engineers generally adopt $\frac{1}{80}$, or 66 feet to the mile, and the French Corps of Ponts et Chaussees recommend $\frac{1}{125}$, or about 42 feet to the mile.

Maximum and Minimum Grades.

As a rule therefore the gradients or longitudinal slopes of a road should be established between 1 in 30 and 1 in 125. It is generally practicable to keep within the maximum of $\frac{1}{30}$, even in locating a line upon a steep hill-side, by giving it a zigzag direction, connecting the straight portions by easy curves.

At the curves the gradients should be somewhat reduced, and the roadway made wider. The increase in width should be about one-fourth, when the angle between the straight portions is from 120° to 90°, and between one-third and one-half where the angle is from 90° to 60°. In descending a hill there is a tendency to overturn the vehicle at the curved portions, from the effects of the centrifugal force, and this danger is in proportion to the speed of the descent, and the sharpness of the turn. The radius of the curve should therefore be great, never, if practicable less than 100 feet. For the same reason, upon all sharp curves, the road surface should not be the highest in the centre, and falling in both directions so as to drain off the water, but should be the highest on the outer or convex side.

In long ascents, it is deemed advantageous to make the lowest portion comparatively steep, with a corresponding reduction in the gradient near the summit, in order that the animals may achieve, while fresh, as much of the rise as possible, while the more gentle slopes are left for the last.

Statical Resistance on Grades.

Returning to Fig. 5 (reproduced in Fig. 6), let us suppose that the horizontal A C is of such length that the vertical rise **h**=1 foot. We then have

$$W : BC :: t : 1,$$

$$\text{and } W : BC :: p : AC,$$

from which we get $t = \frac{W}{BC}$,

$$p = W \frac{AC}{BC},$$

Hence, the force acting parallel to an inclined road necessary to sustain a carriage and load in a state of rest, is equal to the weight of carriage and load divided by the inclined length corresponding to a rise of one foot. And, the normal pressure of carriage and load upon an inclined road is equal to the weight of carriage and load multiplied by the quotient of the horizontal length divided by the inclined length.

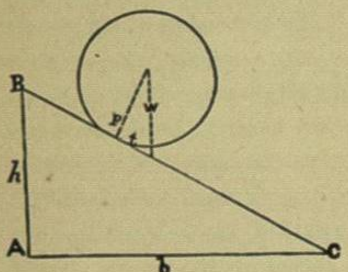


FIG. 6.

For example, the force necessary to sustain a carriage and load weighing 2500 pounds upon a road with a gradient of 1 in 20 is $\frac{2500}{\sqrt{20^2+1}} = 125$ pounds nearly, and the normal pressure upon the road-surface is $2500 \times \frac{20}{\sqrt{20^2+1}} = 2496$.

These results are theoretical. They approximate to practical correctness, as the friction on the axles is diminished, and the smoothness and hardness of the road is increased.

Dynamical Resistances. Sir John Macniell's Formulae.

The following arbitrary formulae have been deduced by Sir John Macniell from a number of experiments upon the several descriptions of road named below, with stage-coaches and wagons moving at various velocities, and carrying various loads. R=force required to move the vehicle; W=weight of vehicle; w=weight of load, all expressed in pounds. v=velocity in feet per second. c is a constant, depending for its magnitude upon the character of the road-surface, which, for the several roads tried, is as follows:

On a timber surface, or on a paved road	c = 2
On a well made broken stone road in a dry, clean state	c = 5
" " " covered with dust	c = 8
" " " wet and muddy	c = 10
On a gravel or flint road, in a dry, clean state	c = 13
" " wet and muddy	c = 32

For a common stage-wagon the formula is,

$$R = \frac{W+w}{93} + \frac{w}{40} + cv,$$

and for a stage-coach,

$$R = \frac{W+w}{100} + \frac{w}{40} + cv.$$

For example, the force necessary to move a stage-coach weighing 2400 pounds, loaded with 2000 pounds, at a speed of six feet per second, upon a level, dry, and clean gravel road, is $\frac{2400+2000}{100} + \frac{2000}{40} + 6 \times 13 = 172$ pounds.

Mr. Law's Table of Dynamical Resistances.

The following table, prepared by curtailing to some ex-

Rate of Inclination.	Angle with the Horizon.			For a Stage-Wagon and load of six tons, moving at three miles per hour.				For a Stage-Coach and load of three tons, moving at six miles per hour.			
				Force required to draw the wagon UP the incline.	Force required to draw the wagon DOWN the incline.	Equivalent length of level road for an ASCENDING wagon.	Equivalent length of level road for a DESCENDING wagon.	Force required to draw the coach UP the incline.	Force required to draw the coach DOWN the incline.	Equivalent length of level road for an ASCENDING coach.	Equivalent length of level road for a DESCENDING coach.
	°	′	″	lbs.	lbs.	Miles.	Miles.	lbs.	lbs.	Miles.	Miles.
1 in 260	0	13	13	315	212	1.196	.8039	387	336	1.071	.9286
" 250	0	13	45	317	210	1.204	.7963	388	335	1.074	.9259
" 240	0	14	19	320	208	1.212	.7876	390	334	1.077	.9226
" 230	0	14	57	322	205	1.222	.7785	391	332	1.080	.9192
" 220	0	15	37	325	203	1.232	.7683	392	331	1.084	.9156
" 200	0	17	11	331	197	1,255	.7451	395	328	1.092	.9071
" 180	0	19	6	338	189	1.283	.7171	399	324	1.103	.8968
" 160	0	21	29	348	180	1.319	.6814	404	320	1.116	.8839
" 140	0	24	33	360	168	1.364	.6359	410	314	1.132	.8673
" 130	0	26	27	367	160	1.392	.6079	413	310	1.142	.8573
" 120	0	28	39	376	152	1.425	.5752	418	306	1.154	.8451
" 110	0	31	15	386	142	1.451	.5491	423	300	1.169	.8308
" 100	0	34	23	398	129	1.510	.4903	429	294	1.185	.8142
" 95	0	36	11	405	122	1.537	.4634	432	291	1.195	.8045
" 90	0	38	12	413	114	1.566	.4338	436	287	1.206	.7937
" 85	0	40	27	422	106	1.600	.4004	441	282	1.219	.7801
" 80	0	42	58	432	96	1.637	.3629	446	278	1.232	.7677
" 75	0	45	51	443	85	1.680	.3204	451	272	1.247	.7522
" 70	0	49	7	456	72	1.728	.2719	457	266	1.265	.7345
" 65	0	52	54	470	57	1.784	.2161	465	258	1.285	.7143
" 60	0	57	18	488	40	1.850	.1505	474	250	1.309	.6903
" 55	1	2	30	508	19	1.926	.0736	484	239	1.337	.6620

tent a table given by Mr. Henry Law, C. E., shows with an approximation to exactness, quite sufficient to make it very valuable, the force required to draw two kinds of loaded vehicles, one weighing with its load 6 tons at a speed of 3 miles, and the other weighing with its load 3 tons at a speed of 6 miles per hour, along a Macadamized road in its usua state, with gradients varying from 1 in 7 to 1 in 600. The table also gives the length of level road equivalent to 1 mile of the inclined road, of each gradient, "that is the length which would require the same mechanical force to be expended in drawing a wagon over it, as would be necessary to draw it over a mile of the inclined road."

Rate of Inclination.	Angle with the Horizon.			For a Stage-Wagon and load of six tons, moving at three miles per hour.				For a Stage-Coach and load of three tons, moving at six miles per hour.			
				Force required to draw the wagon UP the incline.	Force required to draw the wagon DOWN the incline.	Equivalent length of level road for an ASCENDING wagon.	Equivalent length of level road for a DESCENDING wagon.	Force required to draw the coach UP the incline.	Force required to draw the coach DOWN the incline.	Equivalent length of level road for an ASCENDING coach.	Equivalent length of level road for a DESCENDING coach.
	°	′	″	lbs.	lbs.	Miles.	Miles.	lbs.	lbs.	Miles.	Miles.
1 in 600	0	5	44	286	241	1.085	.9150	373	350	1.030	.9690
" 550	0	6	15	288	239	1.093	.9074	374	349	1.033	.9662
" 500	0	6	53	291	237	1.102	.8979	375	348	1.037	.9629
" 450	0	7	38	294	234	1.113	.8869	377	347	1.041	.9588
" 400	0	8	36	297	230	1.128	.8725	378	345	1.046	.9535
" 350	0	9	49	302	225	1.146	.8543	381	342	1.053	.9469
" 300	0	11	28	309	219	1.170	.8301	384	339	1.061	.9381
" 280	0	12	17	312	216	1.182	.8179	386	338	1.066	.9336

Rate of Inclination.	Angle with the Horizon.			For a Stage-Wagon and load of six tons, moving at three miles per hour.				For a Stage-Coach and load of three tons, moving at six miles per hour.			
				Force required to draw the wagon UP the incline.	Force required to draw the wagon DOWN the incline.	Equivalent length of level road for an ASCENDING wagon.	Equivalent length of level road for a DESCENDING wagon.	Force required to draw the coach UP the incline.	Force required to draw the coach DOWN the incline.	Equivalent length of level road for an ASCENDING coach.	Equivalent length of level road for a DESCENDING coach.
	°	′	″	lbs.	lbs.	Miles.	Miles.	lbs.	lbs.	Miles.	Miles.
1 in 50	1	8	6	533	....	2.019	....	496	227	1.371	.6283
" 45	1	16	24	562	....	2.133	....	511	212	1.412	.5871
" 40	1	25	57	600	....	2.274	....	530	194	1.464	.5354
" 35	1	38	14	648	....	2.456	....	554	170	1.530	.46[illegible]
" 34	1	41	8	659	....	2.499	....	559	164	1.546	.4535
" 33	1	44	12	671	....	2.544	....	565	158	1.562	.4370
" 32	1	47	27	684	....	2.593	....	572	152	1.580	.4193
" 31	1	50	55	697	....	2.644	....	578	145	1.599	.4007
" 30	1	54	37	712	....	2.699	....	586	138	1.619	.3805
" 29	1	58	34	727	....	2.758	....	593	130	1.640	.3592
" 28	2	2	5	744	....	2.820	....	602	122	1.663	.3363
" 27	2	7	2	762	....	2.888	....	610	113	1.688	.3119
" 26	2	12	2	781	....	2.960	....	620	103	1.714	.2854
" 25	2	17	26	801	....	3.038	....	630	93	1.743	.2566
" 24	2	23	10	823	....	3.120	....	641	82	1.774	.2257
" 23	2	29	22	847	....	3.213	....	653	69	1.808	.1919
" 22	2	36	10	874	....	3.313	....	666	56	1.844	.1554
" 21	2	43	35	903	....	3.4[illegible]	....	681	42	1.884	.1150
" 20	2	51	21	933	....	3.538	....	696	26	1.926	.0730
" 19	3	0	46	970	....	3.677	....	714	8	1.977	.0221
" 18	3	10	47	1009	....	3.826	...	734	....	2.032	....
" 17	3	21	59	1053	....	3.991	....	756	....	2.092	....

Rate of Inclination.	Angle with the Horizon.			For a Stage-Wagon and load of six tons, moving at three miles per hour.				For a Stage-Coach and load of three tons, moving at six miles per hour.			
				Force required to draw the wagon UP the incline.	Force required to draw the wagon DOWN the incline.	Equivalent length of level road for an ASCENDING wagon.	Equivalent length of level road for a DESCENDING wagon.	Force required to draw the coach UP the incline.	Force required to draw the coach DOWN the incline.	Equivalent length of level road for an ASCENDING coach.	Equivalent length of level road for a DESCENDING coach.
	°	′	″	lbs.	lbs.	Miles.	Miles.	lbs.	lbs.	Miles.	Miles.
1 in 16	3	34	35	1102	....	4.178	....	780	....	2.160	....
" 15	3	48	51	1157	....	4.388	....	807	....	2.234	....
" 14	4	5	14	1221	....	4.629	....	839	....	2,322	....
" 13	4	23	56	1294	....	4.906	....	875	....	2.423	....
" 12	4	45	49	1379	....	5.229	....	918	....	2.540	....
" 11	5	11	40	1480	....	5.611	....	968	....	2.679	....
" 10	5	42	58	1600	....	6.067	....	1028	....	2.846	....
" 9	6	20	25	1747	....	6.623	....	1101	....	3.048	....
" 8	7	7	30	1929	....	7.315	....	1192	....	3.300	....
" 7	8	7	48	2162	....	8.199	....	1308	....	3.621	....

From the foregoing table we see :

1. That the force necessary to move a vehicle at a certain velocity on a level road must be decreased on a descending grade to precisely the same extent that it must be increased in ascending the same grade, in order to maintain the same velocity.

2. It must not, however, be inferred from this that the animal force expended in passing and repassing on the same road, will gain as much in descending the several grades as it will lose in ascending them. The animal force must be

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