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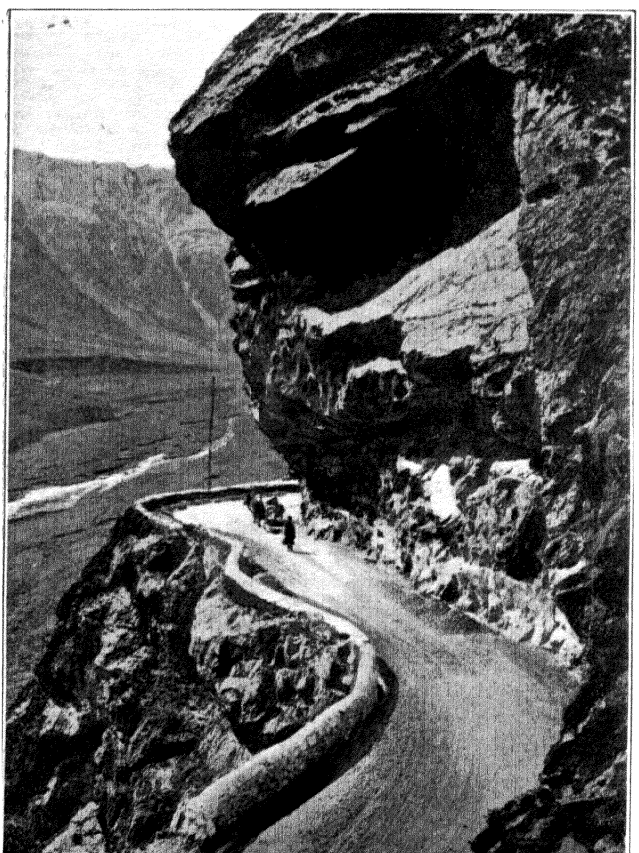
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Author Manual of road

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A Mountain Military Road.

MANUAL

OF

ROAD CONSTRUCTION

AND

MAINTENANCE.

COMPILED AT THE SCHOOL OF MILITARY ENGINEERING BY

MAJOR E. M. PAUL, R.E.,

ASSOC. INST. C.E.

(Instructional Staff).

Chatham:

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PREFACE.

THE need of a Handbook in concise form dealing with Road Construction and Maintenance has prompted the publication of these notes.

No claim to originality is made for the contents.

The author desires to acknowledge the co-operation of many brother officers of the Corps of Royal Engineers in various parts of the world, who have given the benefit of their experience, and furnished useful notes and practical hints.

Most of the illustrations have been contributed by R.E. Officers from photographs of works executed under their charge.

Several members—past and present—of the Instructional Staff of the School of Military Engineering have contributed considerable assistance in preparing the figures and plates, and it is hoped that the Manual may be revised in the future so as to keep it up-to-date.

Few Tables have been reproduced, as it is assumed that R.E. Officers have access to the usual Engineering Pocket Books, and to the several publications on Reconnaissance, Topography, and Military Engineering.

It is hoped that the advertisements at the end of the text may be of use to those using this Handbook.

E. M. PAUL, MAJOR, R.E.,
Instructional Staff.

School of Military Engineering, Chatham,
May, 1908.

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ROADS.

CONSTRUCTION—MAINTENANCE AND COST, CULVERTS AND WATERWAY.

CHAPTER I.

PRELIMINARIES, FOUNDATIONS, SURFACE, ACCESSORIES, ETC.

GOOD roads are a national asset, essential for the prosperity of every country, and, from a military standpoint, furnish invaluable aids for defence.

To connect two points at some distance apart by means of a road seems an easy matter. In reality it is not so, in most cases considerable skill and experience being necessary, apart from the study of principles.

Neglect of main principles has caused many a road to be badly engineered.

A good eye for country, common sense, and knowledge of principles are essentials in a good road prospector.

The subject divides itself into road-building in :—

(*a*). Civilized countries.
(*b*). Partly civilized, or entirely unopened country, mountainous regions, as in India, Africa, Canada, and Colonies.

CIVILIZED COUNTRIES.—The conditions to be dealt with are generally where :—

(1). Wheel traffic is great.
(2). Gradients are easy as a rule.
(3). Land is valuable.
(4). Appliances for repair, etc., are easily obtained.

N.B.—Mountain and hill roads exist equally in civilized countries, but will be dealt with later.

New Countries.

(1). Inhabitants may be hostile, not amenable to labour.
(2). Land of little value.
(3). Labour cheap and plentiful.
(4). Materials for repairs, etc., cheap, although the appliances may be difficult to obtain.
(5). Engineering difficulties in the matter of rivers, swamps, forests, and mountains may be much greater.
(6). Climatic conditions may be unfavourable.
(7). Transport difficulties usually considerable.

In civilized countries the difficulties to be overcome may be equally great, but in new countries, owing to want of existing communication, they are usually emphasized, especially in the matter of transport.

Roads will be considered under the following headings as regards their construction, etc. :—

(1). Preliminaries.
(2). Foundations.
(3). Surface.
(4). Accessories.
(5). Compensation for Damage.
(6). Military Roads in New Countries.
(7). Roads during Military Operations.
(8). Organization of Labour.
(9). Maintenance.
(10). Inspections and Standing Orders.
(11). Prevention of Dust.
(12). Estimates, Specifications, etc., etc.
(13). Approximate Cost of Roads.

Preliminaries.—The first step is the *selection of the route* after careful *reconnaissance of the district* lying between the two points to be connected by road, so as to select alternative routes.

The main considerations which decide the alignment are :—

(1). Shortness, consistent with least rise and fall.
(2). Ruling gradient.
(3). Curves of minimum radius.
(4). Economy of earthwork, culverts, and bridges.
(5). Proximity of quarries, water, villages, or towns.
(6). Strategic and political reasons, trade routes, etc.
(7). Sites for camping grounds and defence during military operations.

RULING GRADIENT.—For wheeled traffic in England there is no fixed limit, but it should not be steeper than 1 in 20. Telford adopted 1 in 30 as a rule.

In France and India the ruling gradient is 1 in 20.

In America the ruling gradient is 1 in 11.

In general, the grade should be reduced to 1 in 35 if possible, which is the best grade for driving fast downhill, and is easy to climb.

1 in 17 is permissible, but 1 in 20 should not be exceeded.

In some hill roads grades as steep as 1 in 10 occur, but the strain on draught and pack animals is very great.

In hill *roads* the *ascending* grade which is practicable for laden carts and bullocks rules. A man walks slowly uphill and quickly downhill; a horse does the reverse, the steeper the ascent, the faster he will attempt to travel until fatigued; hence, steep ascents are most trying to animals in general. For foot and bridle *paths*, for men, ponies, and pack animals, the conditions are again reversed. Men and animals can climb steeper places than they can descend; besides, animals cannot be ridden or retain their loads down steep descents, which, as ascents, are quite practicable; hence, for bridle *paths*, the *descending* grade rules.

A good horse, weighing 1,200 lbs., can pull 1 ton at 2½ miles per hour, 10 hours a day, on a good level road.

On a smooth grade of 1 in 20 he can only pull 40 per cent.

For a short time a horse can exert *twice* the power of an average day's work; hence the resistance of gradient should not exceed twice that of the level.

The following important facts, determined by experiment with regard to animal traction, have been taken mainly from *Roads, Streets, and Pavements*, Colonel Gillmore, U.S.A., p. 21:—

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

2. Resistance is practically independent of the width of the tyre on hard roads, if that width is over 3 inches or 4 inches.

3. At a walking speed the traction is the same for carriages with or without springs.

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

5. On soft muddy roads or gravel the traction is independent of the velocity.

6. Wear and tear varies inversely as the diameter of wheels; it is greater with small wheeled carriages than large, and if without springs than with. It has also been proved experimentally that wheels with 2½-inch tyres cause double the wear produced by vehicles with 4½-inch tyres.

If a wagon and load weigh 1 ton, the following will be the force just required to move it slowly on a level, over different road surfaces :—

(1). Smooth pavement, asphalt ....12 lbs., $\frac{1}{186}$ of load.
(2). Telford road ..... 46 ,, $\frac{1}{49}$,,
(3). Macadamized road ....65 ,, $\frac{1}{34}$,,
(4). Gravel road.. .. ..140 ,, $\frac{1}{16}$,,
(5). Common earth .... .200 ,, $\frac{1}{11}$,,

To apply these facts to the determination of the gradients in a road. If W be the load on an incline i, = angle of repose against sliding, the force required to prevent W from rolling down = the force which would just pull W along on the level, for that is the force required to overcome the friction of the road

Then $\frac{T}{W}$ as $\frac{\text{sine } i}{\text{sine } 90^\circ} = \frac{h}{l}$, *i.e.*, a gradient of h in l (see *Fig.* 1).

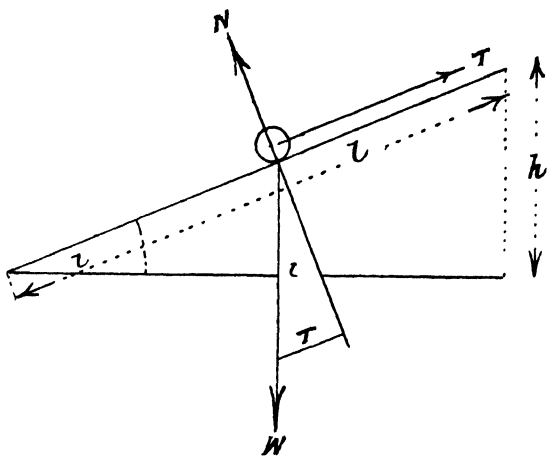


FIG. 1.

Substituting for T and W from the above, we can find the gradient on which 1 ton can be just moved.

$$\therefore \quad \frac{T}{W} = \frac{12}{2240} = \frac{h}{l} = \frac{1}{186}.$$

For (1) smooth pavement. T 12 lbs., W 2,240, a grade of 1 in 186.
,, (2) Telford road. T 46 ,, ...1 ,, 49.
,, (3) macadamised road. T 65 ,, ... 1 ,, 34.
,, (4) gravel road. T 140 ,, ... 1 ,, 16.
,, (5) earth road. T 200 ,, ... 1 ,, 11.

Hence it will be seen that the smoother and better the road, the less should be the gradient ; it is evident that each surface presents to a vehicle a certain angle of repose, which increases with roughness. Practically it comes to this, that on a slightly inclined but very smooth road the horse and vehicle receive less assistance to prevent the load slipping down than on a rough incline, where the

force of friction, tending to prevent sliding down, is greater, and the influence of gravity is consequently felt less. On a smooth pavement, inclined at 1 in 186 (the angle of repose for this class of road), a horse, to pull 1 ton, must exert 12 lbs. to overcome friction + 12 lbs. to draw up the load.

On good hard surface roads a heavy road engine, 10 h.p. (nominal), of weight W will draw :—

On a slope 1 in 10, a load W.
,, ,, 1 ,, 20, ,, 2W.
,, ,, 1 ,, 30, ,, 3W.

Ruling grades for different pavements :—

Wood ....1 in 25.
Stone setts ....1 ,, 40.
Asphalt, powder ....1 ,, 50.
,, mastic ....1 ,, 60.

The disadvantages of steep gradients are :—

(1). Loss of power.
(2) Water from heavy rain tends to damage a road.
(3). Greater wear and tear by draught animals' feet, ascending and descending, and, indirectly, fatigue to the animals themselves, and increased cost of maintenance.
(4). Destructive influence of brakes, slipper drags, skidding wheels.

With the introduction of motor traffic these are, to a certain extent, minimized, and a flatter, impermeable, compact, smooth-surfaced, dustless road becomes an emphasized necessity.

A longitudinal gradient of 1 in 100 to 1 in 150 is desirable for efficient drainage.

In mountain roads a grade of 1 in 20 is rather too steep for *continuous* ascents exceeding five or six miles in length. For such it is desirable to work to a ruling grade of 1 in 25 if possible.

For grade table see Appendix A.

Where long gradients are necessary, let the lowest portion be steepest, and break with occasional stretches of level, or widen at intervals, where teams can be halted, outspanned, and loads lifted whilst resting.

Width of Road depends on :—

(1). Expected traffic.
(2). Land available.
(3). Money available.

In England it is usual to take multiples of 8 feet, that being the width required for one vehicle, *i.e*, a 16-foot road will allow two

carts to pass each other. Ordinary turnpike or main roads are 30 feet in England.

Where the country is intersected with railways, the width* of roadway of various kinds, whether over or under railways, is fixed by law; the minimum is 12 feet, measured over ditches and paths.

To carry a 2nd class road under a railway, 25 feet.
" " 1st " " " 35 "

In general, where land is cheap and can be easily procured, it is as well to allow a few feet extra to the multiple of 8 feet, so as to provide for:—

(1). Metal to be stacked and broken at sight.
(2). Hedges, banks, and ditches.
(3). Against future widening.

A width of 6 feet will suffice for infantry in fours and for pack animals moving in one direction, but a width of 9 feet is desirable.

A width of 14 feet will allow laden animals (including camels and elephants) to pass each other comfortably.

A width of 10 feet is sufficient for loaded wagons and carts, with passing places at intervals; 12 feet will allow mounted men to pass wagons.

A width of 16 feet is the most economical, as mounted men and wagons can pass each other without difficulty, and allows the passage of two columns in opposite directions.

The Grand Trunk Roads of India are 40 feet over all—16 feet metalled (see *Fig.* 23 and p. 32). The section Attock to Peshawar has 12 feet metalled; less important roads have only 8 feet or 9 feet metalled. But the narrow width induces continuous cart tracks and ruts to quickly form.

Footpaths must be allowed for extra; width generally taken as one-fifth of the roadway.

Cross Section.—A much-discussed question as regards "camber." This may either be "barrelled," elliptical in shape, or with flat sides rounded off at the crown. In America a road is specified as "crowned 6 inches or 12 inches" (*Figs.* 2 and 3).

The "formation surface," or "subgrade," should have a regular slope; the rise at the centre is generally 1/60 total clear width between the kerbs.

Radius of curvature of finished metal surface should be about 90 feet. Camber for asphalt, 1/80 to 1/100, clear width; stone setts and wood pavement, 1/60 to 1/80, ditto; as this gradually wears down, the metal must be renewed. For setting out camber *vide Molesworth's Pocket-Book*, 25th edition, p. 672.

* *Molesworth's Pocket-Book*, p. 200.

For modern traffic, the flatter the road contour the better, consistent with drainage of the surface; the provision of a sound even waterproof surface therefore enables the camber to be considerably reduced. In a comparatively dry climate like England, not subject to torrential rains, the tendency is to diminish the camber and fill in the ditches, so as to give greater traffic width, arranging at the roadsides for shallow drainage over the actual metal. In wet climates, where rainfall is excessive, the camber must be increased.

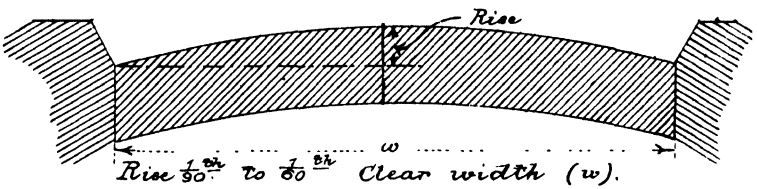


FIG. 2.—*Barrel Section.*

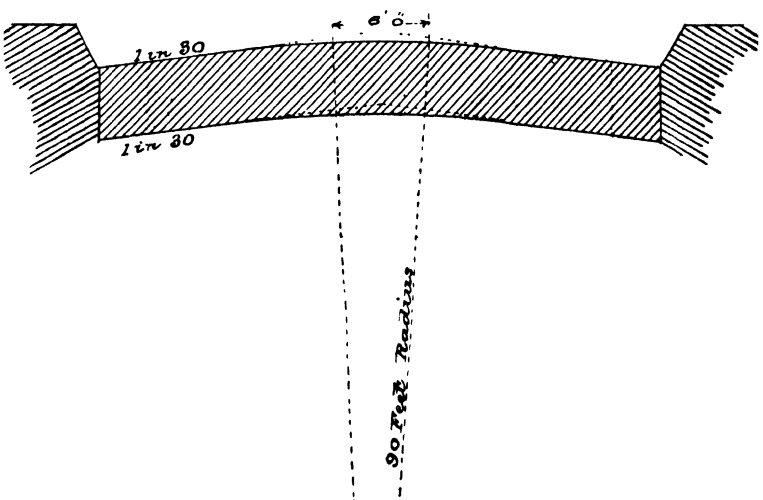


FIG. 3.—*Plane and Curve Profile.*

Excessive camber in general induces the whole of the traffic to keep to the centre of the roadway and produce uneven wear; otherwise the wide wheels of self-propelled vehicles only bear upon the road surface for a proportion of their width. Excessive camber is also dangerous to swift traffic, and adds to the danger of skidding if the surface becomes slippery (see p. 22).

It is advisable to make a "template," or gauge (*Fig.* 4), to secure correct barrelling. On narrow roads a board cut to the curve, edged with iron, will suffice.

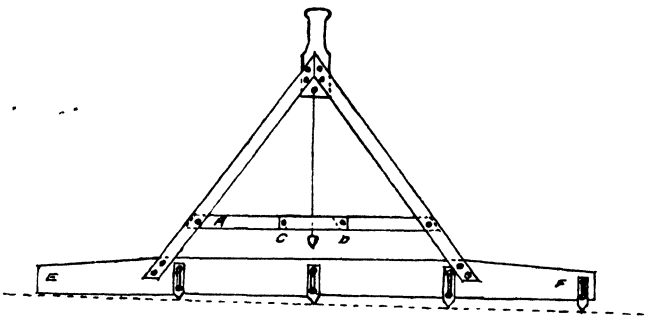


FIG. 4.—*Road Level.*

LIMITING CURVES.—Small wheel traffic can go round much sharper curves than engines or rolling stock on rails.

Except in hills or mountains, *sharp* curves are never required, or very rarely. On a cart road they should not be less than 45 feet radius; if less, the road should be widened to 26 feet clear at the curve.

To find the radius of curvature of a staked-out curve, pegs being equidistant, stretch a string from any stake to the 3rd, 5th, or 7th peg, in either direction, and measure the offset from the peg opposite its middle point (*i.e.*, obtain a middle ordinate). Then radius of curvature in feet = length of string in feet, squared, ÷ 8 times the middle ordinate in feet.

The grades on curves should be eased as much as possible.

Foundations.—The foundation of a road is of the greatest importance, as it is upon this that its strength mainly depends to resist the blows of heavy traffic. Therefore avoid perishable rubbish.

Once put in, the foundation cannot be altered; therefore prepare the subgrade carefully. Chalk forms a good foundation, provided no water gets to it. For very heavy street traffic 9 inches of good cement concrete, made with good hard stone or clinker, is advisable.

In forming earthen embankments in India, Africa, etc., by native labour, the gangs should be compelled to traverse the newly deposited layers, both going and returning to the borrow pits, or source of spoil, so as to assist consolidation of the material.

A bank should be allowed one season to settle before metalling, and the foundation should be 3 inches thicker than on natural ground.

Where good sub-soil, firm and fairly unyielding, is met with, either of the two ordinary methods may be adopted, viz. :—

(*a*). Telford* system.
(*b*). Macadam* system.

TELFORD SYSTEM (see *Fig.* 5).—To be used where stone is plentiful. First a rough rock paving, 7 inches to 10 inches deep, of medium and large blocks is laid by hand, filled in with smaller blocks, and all projecting points broken off, so that when laid the surface may be fairly even.

Essentials and important points:—Blocks—hand-laid, broad end downwards, large and medium sizes—longways across the road; chips and spalls to be wedged in.

The stone used not to be very hard, but durable.

At the sides the "bottoming" need only be about 4 inches thick, so as to give a rise to the foundation.

The object of this foundation is:—

(1). To carry and sustain the blows of heavy traffic.
(2). To prevent earth from the sub-soil being squeezed up.

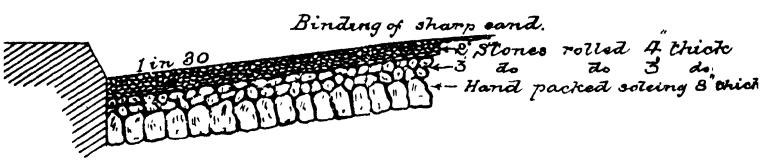


FIG. 5.—*Modern Telford Section.*

The cross section is made up of:—

(1). Foundation, hand-pitched rock, 7 to 8 inches deep, interstices filled with small stones and consolidated.
(2). Layer of 3-inch stone, rolled until 3 inches thick.
(3). Layer of ½ inch of sand or gravel, rolled dry.
(4). Layer of 2-inch stone, rolled until 4 inches thick.
(5). Layer ½ inch sand—*dry.*
(6). Final coating of clean, sharp sand, rolled *wet* until smooth.

MACADAM SYSTEM (see *Fig.* 6).—An entirely different system, more general, perhaps; largely used in India and America.

The rock or stone bottoming is dispensed with.

The road metal is broken to *2-inch ring* and spread over the site in three successive layers, each 3 inches to 4 inches deep, and separately rolled or rammed; thus a firm, compact bed of angular fragments of stone, about 8 inches to 10 inches thick is formed,

* From the names of engineers who practised them.

which should be impervious to water, or nearly so, and which soon acquires a smooth surface.

The advantage claimed over the Telford road is that it gives an elastic bottom, as against the unyielding slabs of rock.

Colonel Gillmore, a well-known American authority, considered that, in either case, the bottoming or metal should be laid first over a layer of fascines ; but this has greater application in soft places on subgrades.

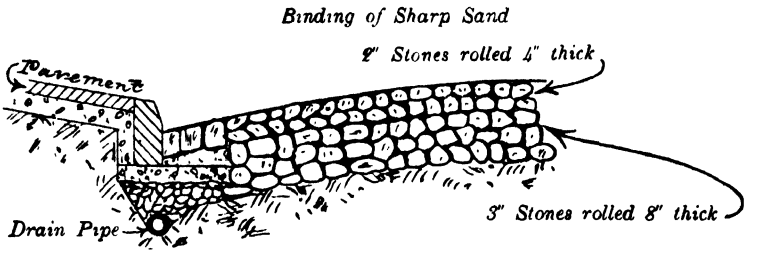


FIG. 6.—*Modern Macadam Section.*

In making a macadam road, drains are dug along the sides and the earth thrown up and spread over the road site, filling in inequalities, and raising it slightly ; the metal is then spread and consolidated in layers—first, 3-inch stones rolled until 8 inches thick, then 2-inch stones rolled until 4 inches thick, finally sand and water spread over the top and rolled.

Defects of Telford Road.—(1). A large percentage of voids in the foundations, which may allow water to percolate and carry away natural soil or else soften it ; the subgrade and foundation then give, and the road sinks.

(2). If the foundation is harder than the metalling, the latter gets gradually pounded up.

Defects of Macadam Road.—(1). It is not quite impervious ; soil will creep up through interstices, which cannot be reduced in the first instance by rolling to less than 25 per cent.

THE MODERN FIRST-CLASS ROAD is a modification of the Telford-Macadam systems :—

(1). Bottoming—12 inches of hard rubbish rolled to 9 inches carefully to proper contour.
(2). 5-inch Thames ballast (or stones and sand) rolled to 3 inches.
(3). 3-inch layer of 2-inch granite rolled down to 2 inches.
(4). 3-inch „ 2-inch „ „ 2 inches.
(5). Sprinkling of sand, well watered, and rolled to a finished surface.

Sometimes (1) bottoming is formed of 6-inch good Portland cement, 1 to 6, or lime, 1 to 4, concrete; then a 3-inch layer of 2-inch granite is laid before the concrete has set hard, which provides a rough "key" to the metalling.

In the N.W. Frontier Province, India, roads are made with a soling of boulders, or pieces of rock, 6 inches to 9 inches thick, with the interstices filled in with small stones and earth. A coat of 6-inch or 9-inch stone metal is spread in two layers, each consolidated separately. The thickness depends upon the nature of the soil. The gauge of the metal should be $1\frac{1}{2}$ inches if to be consolidated by bullock rollers, and 2 inches by steam rollers; hard limestone $1\frac{1}{2}$ inches, softer stone 2 inches.

TAR MACADAM, an old method—in its newer form, *i.e.*, tarred granite, blast furnace slag, limestone, or other metal—is non-absorbent, dust free, easily cleansed, economical in watering (summer) and scavenging; it must be laid in dry weather; it is likely to be very extensively used in future, to lessen the dust nuisance.

It has been largely adopted in Paris, and on the highway between Cannes, Nice, and Mentone. The use of tar macadam doubles the cost of the road, but quadruples its life, and saves considerably in scavenging and watering. An occasional spraying with tar is an improvement.

Gradient slope, 1 in 25 maximum recommended.

Process.—Layers of 2-inch broken stone are warmed on an iron floor to expel all moisture; hot gas tar, 6—8 gallons to each *ton*, is then mixed with hot shovels, and the whole stacked under cover for two months. Also as top dressing, two parts $\frac{3}{4}$-inch stone with one of coke breeze heated, mixed with tar, and stacked for use; or, as an alternative, $\frac{1}{4}$-inch to $\frac{1}{2}$-inch stone alone, with 12 gallons tar per *cube yard*. To be successful, the material must be absolutely dry before being tarred.

The best stone for tar macadam is limestone and Kentish rag—in India, kankar nodules; granite and blast furnace slag are also used.

The foundation is laid as for macadam, then 3-inch layer of 2-inch and $\frac{3}{4}$-inch stuff mixed, and well rolled; dressed with one layer of $\frac{3}{4}$-inch stuff alone, rolled to $\frac{1}{2}$ inch; finish with a sprinkling of $\frac{1}{2}$-inch sand, granite or limestone siftings, well rolled dry; or a flushing of hot tar and $\frac{1}{8}$-inch to $\frac{1}{4}$-inch stone chips rolled in. The foundation surface may be flushed with well-boiled tar or Portland cement grout before laying the tar macadam.

The tar should not contain more than 5 per cent. of water, and not less than 55 per cent. of pitch. Good and bad tar may be chemically the same.

Ordinary gas tar should be boiled until, when cool, it can be drawn out into thread-like filaments.

It should be kept at boiling point for three or four hours; the lighter the tar, the longer should it boil, so as to drive off the ammonia, volatile oils, and water; but avoid overboiling. Refined or distilled tar is better than crude.

Defective tar macadam is due to (*a*) unsuitable stone, (*b*) inferior tar, or (*c*) faulty preparation.

"Tarmac," a patent, made of blast furnace slag, impregnated with tar, appears to be a very good material. Opinions differ as to cost as compared with granite macadam, although the initial cost may be higher (about 10 per cent.). "Tarmac" on a large scale will probably prove more economical to maintain in the long run, whilst the expenditure in scavenging, watering, etc., will be reduced to a very small figure (see Appendix B).

Tar macadam differs essentially from "tarmac," in that in the former the road metal is, in general, merely cemented together with tar, whereas in the latter, by the patent process, the pores of the slag are impregnated, thus excluding wet, and so making the resulting road surface waterproof.

"Tarmac" has one well-marked fault, namely, that the slag wears to a very fine state of subdivision, producing a slippery mud which, under the influence of frost, is an element of risk to traffic.

"Slag tar macadam" and "Tarlithic" are proprietary materials which promise well.

Impregnation of metal with tar is believed by some to be the real secret of successful tar macadam, but not solely so; softer metals will absorb more and wear down quickly, producing more dust than hard metal; a hard metal which breaks with a fracture sufficiently rough to secure thorough adherence of the tar seems equally essential. Hard, rough porous blast furnace slag and granite fulfil these requirements. Further remarks upon the employment of tar as a "binder" and for "sealing" the road surface are given on p. 105.

Roads over Marshy Ground.—Where a road is to be made over a swamp or marshy ground, the site must first be treated so as to provide a firm foundation, otherwise the road will certainly sink after it is made.

One method is to make shallow trenches, V-shaped in plan, 2 or 3 feet deep, 20 yards apart, and fill with coarse gravel or rubble stone, draining to side channels.

A careful system of drainage, which will remain clear and unobstructed, is essential; side drains require to be wider and deeper than under ordinary conditions.

On very soft spongy ground, tree trunks, logs, reeds, sapling mats, fascines, coarse grass, millet stalks, or brushwood in bundles 9 inches to 12 inches diameter, about 20 feet long, are laid alternately, and pegged down lengthwise and crosswise, 18 inches thick, until a grillage is formed; if alternately wet or dry, it will soon decay; gravel and road metal is then spread over the top. The top row of fascines must lie across the direction of traffic.

If there is much wheeled traffic, a reserve of material should be collected and prepared to make good hollows and damage.

The most troublesome thing to meet is a small stream in marshy ground; each case must be dealt with on its merits, but in general it is advisable to canalize and train the stream to a definite line, with fascines, etc., cut from long grass and reeds, which are usually to be found on marshy sites.

In the construction of durable roads across low-lying lands, such as salt marshes and meadows situated by tidal estuaries, the chief trouble is that the road must possess the rather opposing characteristics of lightness and strength—lightness in order that it may not sink into the soft ground on which it is laid, and strength in order that it may resist the wash of the waves that may occasionally flood it during stormy weather. Naturally these two qualifications are not always easy to obtain. As a means of securing a foundation for such a road, large trees, with two opposite sides flattened, may be laid lengthwise, one being placed in the centre and one on each side of the road, the outside ones being placed about under where the wheels would pass. Poles about 3 inches in diameter at the small end should be laid across these, the space between the stringers having been first filled with earth and stones or shingle. At each side, over the ends of the poles, $2'' \times 6''$ kerb planks are placed, securely fastened, edge up, to cedar piles driven 6 feet into the ground, and projecting 4 feet above the planks. The piles are placed 8 feet on each side of the centre line, thus giving a 16-foot roadway. Against the outside of the planks a mud bank is carefully thrown up and consolidated; grass growing through this helps to secure it. On the inside of the planks a line of compact earthen bank, about 2 feet wide, forms an almost water-tight trough. Earth and stones can then be filled into the space between the kerb planks and brought level with their tops. Shells, gravel, and shingle, three bushels per square yard, can be spread and consolidated by rolling to a thickness of 6 or 8 inches. This form of construction gives an elevation above the tides, except during severe storms. This road, though topped by storm-tides, is likely to withstand them.

Fascine Roads in Norway.—Made of fir baulks, etc., laid lengthwise and crosswise, with branches and twigs ("lop and top"), and finished off as in *Fig.* 7.



Fig. 7.—*Fascine Road over Marsh, Norway.*

Another plan is to drive short piles and top them with brushwood or fascines; hurdles on a layer of dry peat, stone ballast on top, are sometimes used.

CORDUROY ROADS are often constructed in forest tracts where timber is plentiful. Trees with straight trunks, fairly uniform in size, are felled and laid transversely to the road; charcoal, clay, sand, and gravel, and stones or other suitable substance, is then spread over to pack in between the trunks; a certain amount of rough adzing may also be done to improve the surface inequalities and reduce the slippery surface where the bark has stripped. At best, such roads are only temporary, as they deteriorate with use.

Ribands should be provided and pegged to the logs.

ROADS ACROSS SAND AND DESERT.—In Upper Sindh, where the whole country is a sandy plain, without a stone for miles, the road surface is formed by spreading layers of "moonj," a long reedy grass somewhat like pampas grass. The reeds are laid transversely, and a little sand or loam on top. Permanent improvement is hardly possible, but incorporating fine clay till the sand and clay harden is beneficial.

In China millet stalks (kaoliang) are used for the same purpose.

In parts of Afghanistan similar plains exist, besides mountains and hills, but *no grass*, so that little or nothing can be done in such tracts.

In forest land charcoal makes very compact roads, and they are easily and cheaply made.

Surface.—It is essential that the surface shall provide:—

(i.). A waterproof covering.
(ii.). A wear-resisting medium to protect the foundations.

Failure in road-building will certainly result if neither principle is satisfied.

The heavier the traffic, the harder and more compact must be the metal and road surface.

Traffic is therefore the determining factor in the *life* of a road.

In *self-propelled* traffic four factors govern road wear, viz., (i.) axle load, (ii.) tyre width, (iii.) wheel diameter, (iv.) camber.

The size of metal should be limited to 2 inches every way—generally spoken of as 2-inch ring, *i.e.*, will pass through a ring 2-inch diameter; *one*-inch ring for hand laying; it should be laid in 3-inch layers, so that the top layer comes rather above the finished surface.

The essentials in metal are :—

(1). *Toughness.*—To offer resistance to being broken up, but yet to be breakable, though not flakey; it should break into cubical pieces.

(2). *Resist Abrasion.*—*i.e.*, corners should not easily knock off. The test is to revolve a certain quantity in a closed cylinder with perforated sides a certain number of times, and compare weights before and after.

(3). *Resist Compression.*—Test by placing under a lever.

(4). *Not suffer Decomposition* on exposure to weather or frost; a very porous stone is bad.

The cheapest stone is not always the best.

The following are a few varieties of metal :—

Basalt.—Imported Rhenish basalt is a hard, close-grained, excellent metal.

Syenite.—Good ; the darker the better.

Granite.—Good ; the closer in texture the better.

Trap, basalt, and other igneous rocks are good, *e.g.*, Scotch whinstone.

Gneiss and *Quartzose* rocks are friable and do not last.

Laterite and "*Moorum*" in India make good surfaces, but do not stand much heavy traffic (see p. 94).

Flint is fairly good, but too brittle ; should only be used in default of better stone or material ; flints picked off fields are better than those from chalk pits.

Kentish Rag is a fair metal, but inferior to granite, etc.

Limestone.—Generally good, except oolitic and lias. Too weak for heavy traffic. The chief objection to limestones is that they are dusty in summer, greasy and muddy in winter ; a good all-round metal, especially useful for tar macadam.

Overburnt Brick.—If uniform clinker – good.

Clay-slate and *Sandstone* are bad.

Blast-furnace Slag is hard, angular, and heavy ; not a good binder, but absorbs tar, and is more durable than limestone.

Kankar.—A calcareous deposit, a species of "tufa," is largely used in N.W. India, and makes good roads. It is found as nodules mixed with a good deal of earthy matter ; it is also dug out from quarries in blocks. Block kankar is inferior to nodule kankar (see p. 94). "Bechwa" with blue fracture is the best.

N.B.—A very hard sharp stone metal is destructive to horses' feet. The harder the metal, the smaller should be the gauge.

ROLLING.—Metal should be properly consolidated by rolling or ramming each layer separately as laid, and not left to be worn

smooth by traffic, as the surface is sure to become uneven, and the horses' feet will suffer.

A new road *unrolled* will never be used if it can be avoided by detours or side tracks.

Rollers used—either steam or hand; their weight should not exceed 10 to 15 tons, for they will otherwise be likely to break pipes under the roadway or crush the metal; if too wide, they cannot maintain a proper contour of cross section.

Commence by rolling the sides, or "haunches," so as to press up the metal towards the centre, and finish off at the centre.

Rolling should be done at least five times *dry* before finishing with water and binding material, such as sand, gravel, or granite chips, or screenings, and then rolled 20 to 30 times. This binding is spread from shovels in front of the roller, and water *sprinkled* as well. The binding fills in spaces and keeps the metal together.

About 15 to 20 per cent. of good binding, *evenly spread*, is required for every 100 tons of metal.

Mud or road-scrapings should on no account be used (see also p. 103).

"Hard rolling, minimum of binding," is a good maxim.

Men should keep sweeping the roads behind the roller and the cylinders, so as to ensure every cavity being filled.

A few days should elapse for the road to dry before regular traffic is allowed over it; nothing is likely to do more harm to a newly made-up or repaired road than premature use by vehicular traffic.

Bullock rollers are used in India, ox rollers in South Africa, etc.; those with *reversible poles* are best; increased weight with water ballast.

PAVING OF STREETS.—Various materials are employed—stone, wood, asphalt, India rubber, etc.

Stone Setts or "*Cobbles*" are very durable (Roman roads).

In England granite "setts," cubical blocks, 3 inches to 4 inches square, or $3'' \times 7'' \times 9''$ in section (9 inches depth, 7 inches across the road, 3-inch grip for horses' hoofs), are laid on a solid base, formed of broken stone or of concrete (see *Fig.* 8). Setts of Aberdeen granite are superior to setts of Norwegian granite.

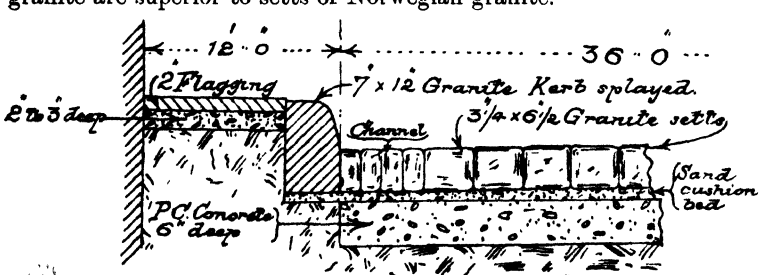


FIG. 8.—*Cross Section of Pitched Pavement.*

Fine gravel or sand is scattered over the top to act as a cushion; it saves wear and reduces noise; the granite setts are arranged fairly close upon this. "Cobbles" are about 3 inches square in plan. The interstices are filled with hard, dry, very fine shingle, and a mixture of hot creosote oil and pitch* run in gradually to deaden the sound. The setts are rammed home with paviours' mauls ("beetles"), the sand being spread over the surface, so as to gradually work its way down. Allow six or seven days to elapse before traffic

Some setts are wedge-shaped, the narrow end up and small chips or wedges of granite are driven in between with fine sand; others equal ended. Sometimes a stiff, though not very rich, cement mortar or grout is run in; bituminous grout* is by far the best for reducing dust.

In streets on an incline it is a good plan to project each course $\frac{1}{4}$ inch to provide foothold, and arrange the setts diagonally, as this assists the flow of surface water to the side drains; also at corners to herring bone, so as to ease the turns.

Granite setts are liable to wear smooth and get depressed, and the street becomes slippery and uneven; the addition of sand as a remedy tends to increase the polish; water cleansing is alone effective.

"Random" setts are undersized irregular setts, only suitable for third-rate roads.

"Kleinpflaster"—variously known as "Durax" or "Cubette"—is a sort of hand-packed, "random," uniform-sized granite sett paving in intersecting curves, and when truly laid forms a sort of mosaic. Sizes—$3\frac{1}{2}'' \times 3\frac{1}{2}''$, with $\frac{1}{2}$-inch variations; depth, 4 inches. Very little dust is formed, which fact chiefly commends its use. It will stand very heavy traffic, lasts long, is clean and easy to lay; it is less noisy than ordinary setts, and the edges of the cubes do not spall.

Concrete as a foundation is very advantageous; it forms the best unyielding surface, and protects water and gas pipes from frost in cold climates.

In some places, *e.g.*, Leicester, $3'' \times 3''$ granite setts have been successfully bedded on $2\frac{1}{2}$ inches of *tar* concrete, overlaying a 4-inch *cement* concrete foundation. The setts are wedged up with chippings, and finally grouted and rammed in with pitch and tar.

On the Continent (old Italian towns, Messina, etc.) streets have been paved with square slabs, set diagonally; the traction is smoother than setts, and they are more easily cleaned, but if the stones become worn or broken, which latter is very likely to occur, they are more expensive to replace.

* Pitch, 3 parts; creosote tar, 1 part (or creosote tar, 8 gallons to boiled pitch, 3 cwt.).

The most perfect granite surfaces are to be seen at Hamburg, where large setts are used, cut and laid with great accuracy, so that the joints are very fine and good ; except for the clatter of animals' hoofs, this type of street pavement is practically noiseless.

The disadvantage of stone setts or cobbles lies in their being :—

(1). Noisy and jarring.
(2). Slippery and greasy in muddy weather.

N.B.—It is dangerous for road engines in wet weather to attempt to ascend or descend grades steeper than 1 in 14 laid with granite setts.

Other materials, mainly proprietary, are :—

"*Quarrite.*"—Limestone treated with a tar preparation.
"*Taafelt.*"—Granite, ditto, ditto.
"*Tarlithic.*"—Blue Fifeshire granite treated with tar.
"*Strongite.*"—Granite set by chemical action with limestone and *wood* tar.

Wood Paving in some respects is better than stone :—

(1). Less noisy.
(2). Safer for horses if kept clean.
(3). Easily swept and cleansed by flushing.
(4). Traction good.
(5). Easily repaired.

The disadvantages are :—

(1). Absorbent, and consequently unhealthy after a time, especially soft wood block.
(2). Liable to decay.
(3). Liable to swell from moisture.
(4). Slippery in wet weather.
(5). Cannot withstand heavy traffic.

Australian Hard Woods.—Jarrah and karri, cherry-coloured woods from West Australia, equally good. Jarrah burns to a *black* ash ; karri to a *white*. Karri shrinks, and is less absorbent than jarrah.

Red gum, blackbutt, red mahogany (N.S. Wales)—the latter very similar to jarrah—are efficient substitutes.

Tallow-wood—canary yellow to pale brown in colour, from N.S. Wales—shrinks less, and is very good.

The weight of all these hard woods is about 55 to 70 lbs. per cubic foot.

Pyinkado (Burma) is good.

Avoid stringy bark, blue gum (Tasmania), and *American* red gum.

"Prismatic oak," an English compound block of oak, is believed to be sound and useful.

Soft Woods.—Creosoted or "carbolened" yellow deal (Baltic fir) and other soft woods impregnated with coarse sugar (Powell process) are said to give good results. Red deal (St. Petersburg or Viborg is best. Swedish yellow deal is largely used.

In general, experience shows that Australian and American hard woods wear unevenly; fine-grained creosoted yellow deals of *well seasoned* timber hold their own for moderately heavy traffic.

Blocks 3 inches wide by 6 inches by 8 inches or 9 inches long are usually employed. Nowadays the depth seldom exceeds 5 inches or 6 inches (hard wood), often only 4½ inches; soft woods, 6 inches. Deeper blocks are wasteful, more costly, and less stable.

Formerly the blocks were laid on a cushion of sand on a concrete bed, and grouted with a cement mortar, and the surface run all over with hot coal tar, upon which fine sand or gravel was scattered.

Blocks are laid end on to grain; all sappy wood and split blocks must be picked out and rejected. A margin of a few inches should be left near the kerb to allow for expansion of new blocks after wet; with *un*creosoted blocks, 4 inches to 5 inches for a 40-foot road; with creosoted blocks, 1 inch for 40-foot, 1½ inches for 60-foot, 2 inches for 80-foot road widths.

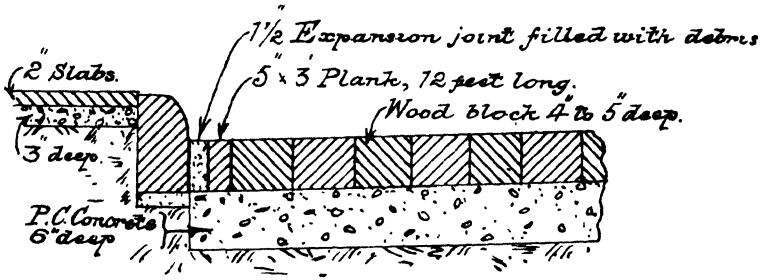


FIG. 9.—*Cross Section of Modern Wood Pavement.*

The more modern method is to lay on concrete as before, but each block is dipped in pitch as laid, and set close up without joints; or a thin grouting of pitch may be poured into the joints, but the former is preferable. Fine chips of stone, gravel, or sand are sometimes sprinkled at the finish, but are not necessary. They only coagulate with the tar and form a sticky mud, which must subsequently be scraped off. Hard wood blocks are close jointed and hammered up at every twelfth row (*vide Fig.* 9).

It is essential to prohibit traffic, to let the concrete set after the wood blocks have been laid; ¼-inch spaces between the rows of blocks are filled in with tar and asphalt, etc.

Wood paving is best laid in hot weather.

Asphalt.—Manufactured from natural rock asphaltum, which is carbonate of lime, with 5 to 15 per cent. of bitumen.

Asphalt is usually laid on a concrete foundation (Portland cement—not lime, which sometimes "blows"), floated with cement. It is laid either as a powder or a viscous fluid.

Powdered or Compressed Asphalt.—1/10 inch mesh, heated to 250° F., laid hot, 1½ inches to 2 inches thick, rammed with hot rammers; then rolled with 12-cwt. rollers till cool. Sand sprinkled on top. The heating fuel should be coal, peat, or hard wood, not coke (which is injurious).

Mastic Asphalt.—An artificially prepared compound; limestone, 85 per cent.; bitumen, 15 per cent.; sold in blocks. To lay it, break up the blocks and add a little bitumen; heat in a cauldron and add grit.

The proportions average per ton—

Asphalt, blocks (½ cwt. each)	12½ cwt.	
Refined bitumen	¾ ,,	or less.
Sharp grit, ½-inch mesh, limestone preferred	6¾ ,,	,, more.

In tropical countries increase the proportion of grit and reduce the bitumen.

In melting asphalt it is essential to keep the cauldron covered, to prevent the escape of volatile oils. At the start melt a little bitumen in the cauldron before adding the asphalt.

"Cooking" occupies four to six hours, and it must be constantly stirred. When the material is properly "cooked," jets of blue smoke are emitted from the surface, and the material will not adhere to a rod thrust into the mass. Care must be taken to prevent the mastic burning. All burnt pieces must be thrown out.

Asphalt should never be laid in wet weather, or at a temperature below freezing point; the surface of a concrete foundation must be quite dry before laying.

Granite Asphalt.—*Granite asphalt has now been used in Paris for some years with most satisfactory results. The substance consists of various minerals, notably granite chippings, mixed hot in an ordinary tar-boiler with natural asphalt. A thorough incorporation at a proper temperature is requisite, and it is claimed that the constituents react on each other. Granite asphalt is unaffected by acids or oils; its hardness, which is not reduced by moderate heat, is generally in excess of that possessed by ordinary asphalt, and though admittedly inferior to granite in this respect, it is practically equal to the sandstones of Fontainebleau. One of the

* Extract from *Le Genie Civil*, Paris, Vol. XLV., pp. 434–6, quoted in the Minutes of Proceedings of the Institution of Civil Engineers, Vol. CLX., pp 417.

advantages claimed for the substance is that a street laid with it can be easily patched without a total relaying, which would be necessary if setts were used.

Advantages of asphalt :—

(1). Smooth.
(2). Clean and very sanitary.
(3). Durable—life, 15 to 20 years.
(4). Uniform in surface.
(5). Healthy.
(6). Little or no noise.
(7). Easy traction.
(8). Comparatively cheap and easy to lay and repair.

Disadvantages :—

(1). Initial cost heavy.
(2). Unsuitable for grades.
(3). Slippery if not kept *quite* clean, and then causes skidding.
(4). Melts in hot climates, and "creeps" if the slope exceeds 1 in 60.

It is much used in London, Berlin, and Paris.

There are several good companies — Val de Travers (Swiss), Seyssel (France), Limmer (Hanover), Trinidad, etc.

The supply and laying of asphalt form a special contract on W.D. work.

India Rubber.—This has been used in Hanover, laid in large sheets 1 inch thick. It is almost perfect, except for the expense.

It has also been tried at the approaches to hotels and public buildings (*e.g.*, the entrances to Euston Road Station and the Savoy Hotel), but the cost is prohibitive for streets.

Cork Pavement is a patent elastic material composed of ground cork mixed with bitumen and fibre ; it is compressed into blocks about the size of an ordinary brick. It is laid in hot tar on a firm foundation, coated over with hot tar (1 gallon) and tallow (4 ozs.).

The cork blocks are dipped in a jointing mixture composed mainly of asphalt, and laid like wood paving.

It is claimed that the paving is non-absorbent, non-slipping, and practically noiseless.

It has been used in Nottingham, Bournemouth, Windsor, and York, and by some of the Railway Companies, with varying success.

The cost is about 10s. 6d. per square yard in London, exclusive of foundation.—*Roadmaking*, etc., T. Aitken, p. 366.

As a summary of suitability of pavings for *animal* transport, the best of all is dry wood block, and the most dangerous dry granite setts.

PREVENTION OF SKIDDING.—With the introduction of motor vehicles the construction of a road surface which will reduce "skidding" is an important consideration.

Any such expedients as studs, spikes, sharp-edged tyres, etc., is to be deprecated.

A bad, improperly kept road surface, aided often by a needlessly high camber, forms a dangerous track to travel on.

Wood holds the field at present, but creosote oil on wood tends to make this kind of pavement slippery; cork may prove useful; asphalt must be kept scrupulously clean.

Tar paving is uncertain for streets with more than the lightest traffic. Flint gravel is cheap and quiet, and the least greasy. Setts of granite, etc., are satisfactory, though noisy.

When a road surface is dry, sideslips will not occur; when a road has a sticky mud, as from limestone, metal, etc., it is best to liquefy and remove the mud by copious flushing with water from fire hose (Gibraltar).

Judicious scattering of shingle and screenings will always prevent skidding; but as fast as this is ground to mud it must be removed. Shingle of flint cuts rubber tyres, but preserves its grittiness longer than granite screenings.

Accessories.

(1). Footpaths and sidewalks.
(2). Water channels and drains.
(3). Kerbs.

FOOTPATHS.—With slight slope, 1 in 90, towards the gutter, allowed for in the foundation. The materials used are:—

(*a*). *Gravel.*—Fine stone chippings, clinker from refuse destructors or ashes (only admissible in country roads where there is little traffic).

(*b*). *Tar Pavement.*— Of gravel, tar, and furnace slag, stone, etc.
Coal tar, 1 cubic foot.*
Stone, $\frac{1}{4}$-inch, $\frac{1}{2}$-inch, $\frac{3}{4}$-inch, $1\frac{1}{4}$-inch gauge, 12 cubic feet.
If damp, the stone should first be heated. The whole is rammed, or rolled with $\frac{1}{2}$-ton roller; larger stones first layer, smallest top layer.

(*c*). *Asphalt.*—Either mastic or powder compressed, on a concrete foundation.

* *Alternative.*—Tar, 12 gallons; pitch, $\frac{1}{2}$ cwt.; creosote oil, 2 gallons; screened aggregate, $1\frac{1}{4}$-inch gauge decreasing to $\frac{1}{4}$-inch, 1 ton.

(*d*). *Slabs or Flagstones.*—Yorkshire stones, so-called "Silex" brand, are good, and it is believed will last 20 years under constant traffic. Usual thickness, $2\frac{1}{2}$ inches to 3 inches.

A foundation, 3 inches or 4 inches of broken brick or gravel, well consolidated, is usually given; some poor mortar is spread over this to level up for bedding the flagstones. Even bedding is essential, and there should not be more than 14 stones per 108 square feet of paving. Edges must butt true and square, and the joints be grouted up. Slabs 2 feet square are usually laid to break joint with 1-foot or 18-inch closers (see *Fig.* 10).

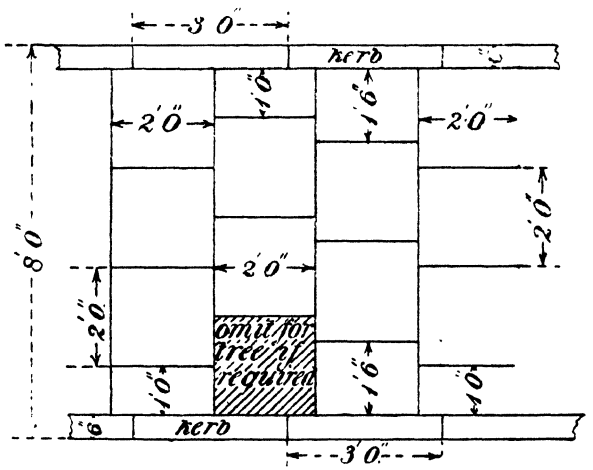


FIG. 10.—*Flagstone Footpath.*

(*e*). *Concrete.*—1 Portland cement to 4, 6, or 8 of aggregate, finished with $\frac{1}{2}$-inch granite siftings. It should be laid in 6-foot bays, or else as separate moulded blocks. Usual depth, 4 inches to 6 inches.

(*f*). *Bricks or Tiles* laid flat or on edge—uncommon except in villages in the Midlands. Blue Staffs. or "brindles" are the best, being less slippery. Burgess Hill clinker bricks and Candy's buff vitrified bricks are also very good.

This paving is cheap and easily repaired, but is liable to wear irregularly and sink down.

Sidewalks.—These are most commonly made now of cement concrete *in situ* or of purpose-made blocks. The proportions may be 1 of cement to 4, 5, 6 of aggregate—granite chippings the best.

A foundation of 4 inches of consolidated clinker or brickbats is well rolled in the first instance. A bottom layer of 1½ inches of granite chippings (⅜ inch), 2 parts to cement 1. Top layer, ¾ inch to 1 inch of finer chippings and cement 2 to 1, well trowelled and kept damp.

N.B.—A thickness of 4½ inches, with 1 inch of good cement mortar finishing coat laid on *at the time*, is better than 6 inches floated over with a thin skin of cement dusted on. The surface is sometimes "pitted," to render it non-slipping, by impressing a block of wood with metal studs over the face.

The following precautions should be noted:—

(1). Use clean sand, especially in the wearing coat.
(2). Use the same brand of cement throughout.
(3). Thoroughly mix the sand and cement dry, adding merely sufficient water to bring the mortar to the consistency of a moist brown sugar.
(4). Thoroughly mix the mortar and aggregate till each stone is coated, and consolidate by light ramming, particularly at the edge.
(5). Avoid long slabs, and also broken joints. A width of 4 feet to 6 feet, with jointing strips, is sufficient for each slab.
(6). Clean the concrete bed thoroughly before applying the wearing coat, which should be put on before the former sets, using pressure in trowelling.
(7). See that the plane slopes true.
(8). Keep the walk damp for several days.

(Extracted mainly from Baker's *Roads and Pavements*, p. 613).

N.B.—There are various patent artificial stone flags on the market. "Non-slip" (hard Yorkshire stone) paving is much used (cost, 7s. per square yard, laid complete).

WATER CHANNELS, ETC. (*Fig.* 11).—The channel or *water "table,"* as it is called, is very important, and trouble should be taken in preparing and laying.

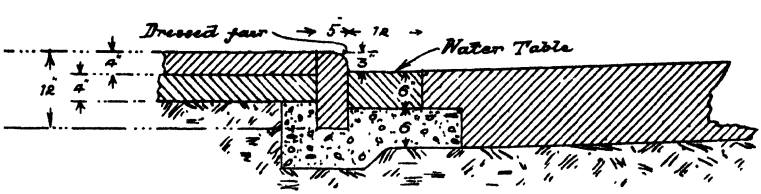


FIG. 11.—*Stone Kerb and Water Table.*

Without side drains, whether in streets or country roads, the haunches of the roads will become damaged by rain. In streets the kerb acts as a wheeler for vehicles.

In *Streets* they may be either of concrete or stone. If stone slabs or setts, they should be bedded solidly and grouted with cement or bitumen.

The channel should slope 1 in 250, the slope being made in setting the table, independent of the kerb, if the road has a less gradient than 1 in 250.

To prevent a continuous rut forming next to the edge of gutter, insert stones as headers when laying the stone slab water tables (*Fig.* 12).

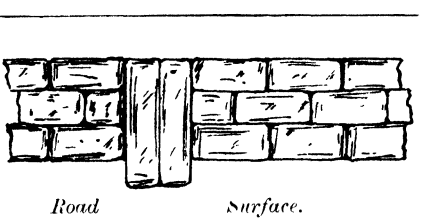


FIG. 12.—*Gutter in Plan.*

These channels discharge the water and silt either through gullies (various types—Grosvenor slanting bar grating, etc.) and "buddle holes" at intervals into conduits under the street leading to the sewers or drains; these must be trapped, without exception, so as to disconnect from foul drainage conduits.

A silt trap should be provided, and cleaned out *regularly*, as a good deal of mud, leaves, and refuse would otherwise get into the conduit and choke it.

The cover or grating should offer no obstacle to traffic; duplicates should be kept to replace broken gratings without delay. The bars should never be parallel to the direction of traffic.

The drainage of all *country roads* is very important (see p. 67).

A water-logged road soon cuts up.

In country roads ditches are dug at the roadsides, preferably beyond the boundary hedge if close to the haunches, when the land is dear and the strip of road site narrow (*Fig.* 13) (see also p. 7, under camber).

They are usually 2½ to 3 feet deep, and if close to the road may be filled up with a blind drain of stone slabs and stones, with brushwood on top, so as to prevent accident from a vehicle going into one.

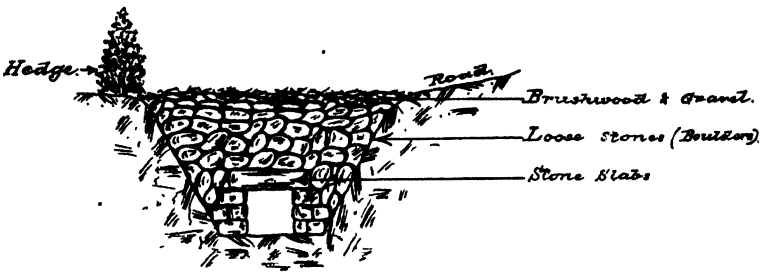


FIG. 13.—*Ditch, Country Road, with Blind Drain.*

Where a road is made in side-long ground, or in cutting, drainage of the slopes above is effected by "catch-water drains." Each site must be dealt with on its merits, remembering that the main thing is to divert the water from the road site as quickly as possible (*Figs.* 14 and 15).

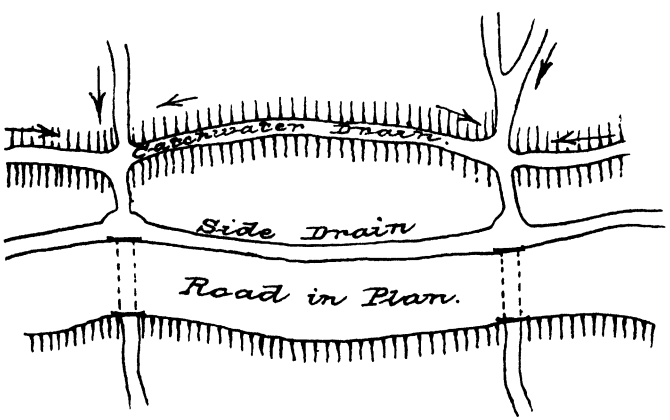


FIG. 14.—*Catch-Water Drainage.*

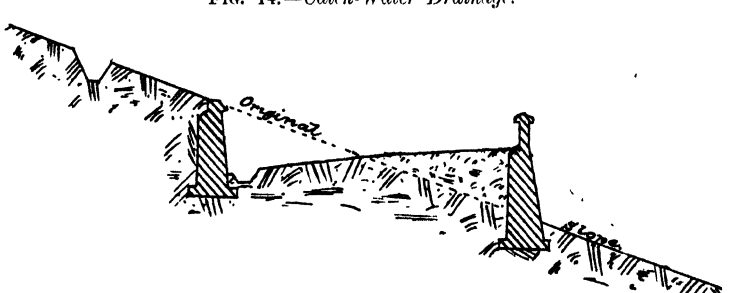


FIG. 15.—*Section.*

KERBS.—These are of stone, iron, or concrete, sometimes hollow, forming conduits for electric cables, etc. (see *Figs.* 16—22).

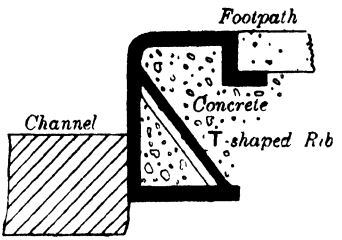


FIG. 16.—*Cast-Iron Kerb.*

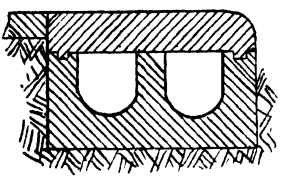


FIG. 17.

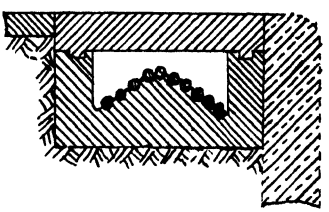


FIG. 18.

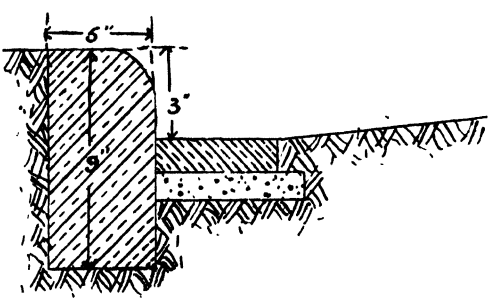


FIG. 19.

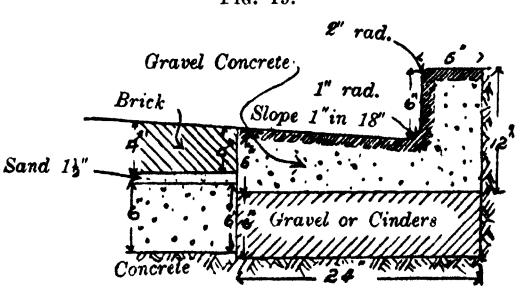


FIG. 20.—*Standard Concrete Kerb and Gutter.*

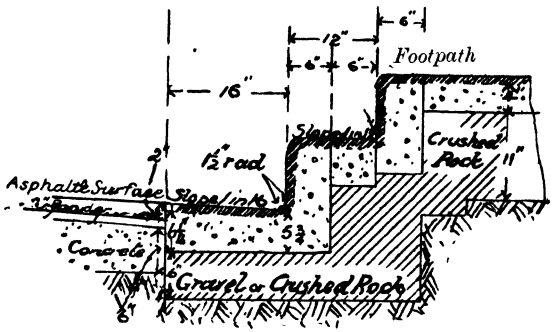


FIG. 21.—*Double Kerb and Gutter.*

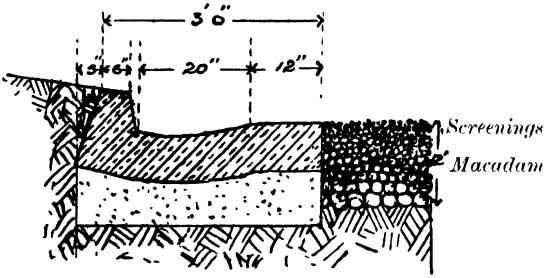


FIG. 22.—*St. Louis Concrete Kerb and Gutter.*

Iron kerbs are costly, and liable to expand, wear smooth, and become slippery.

They are usually of very hard stone (Syenite granite), split into slabs of 3 to 6-foot lengths, at least 9 inches deep and 4 inches wide. They should be dressed partially (only on the exposed faces), bedded in cement, and rammed with packing at the sides to prevent shifting.

Stone kerbs should have a 1-inch draft margin, and clean, sharp arrises at the sides and ends, to butt true.

Their depth should be regulated so that the thrust of the earth and path behind shall not cause the blocks to tilt.

Kerbs, as in *Figs.* 20 and 21, are very usual in America, and are found satisfactory. The final surfacing is made with Portland cement mortar, 1 to 1½ or 2, laid whilst the concrete bedding is fresh and unset, so as to secure an intimate attachment. The face is finished by being floated, trowelled, or brushed.

PARADES.—The principles underlying the construction of metalled roads apply equally in the making of parade grounds—barrack squares—for drill purposes.

Before laying the metal or gravel filling, the formation surface should be graded to the required falls to correspond with the proposed finished surface of the parade, to ensure proper drainage.

Foot parades should be formed of 4 inches of hard filling and 3 inches of screened gravel, fine stuff for binding being added as required.

Parades for mounted troops should have 4 inches of filling and 4 inches of hard stone, broken to 1½-inch gauge, with sufficient fine screened gravel to fill the interstices.

The surface should be currented to the surface channels and well rolled with a steam roller.

To reduce dust the surface may be treated with refined tar, sprayed on hot (see p. 104). It is possible that the Gladwell system of road repair may prove effective for parade grounds (see p. 105).

The following are suitable for hard filling and gravelling :—

Burnt clay, ballast, quarry siftings, chippings, forge and furnace ashes, clinker, slag, and flints.

(*Design and Construction of Military Buildings*, p. 14).

Compensation for Damage to Roads.—Compensation is frequently claimed for damage due to "extraordinary traffic," *e.g.*, by troops and vehicles over a manœuvre area temporarily occupied for military operations in peace.

A "Road Compensation Officer" is usually appointed to assess the compensation for damage.

The following points should be borne in mind when detailed for such a duty, after being provided with a 6-inch map of the whole area :—

1. Ascertain what local authorities maintain each road. For this purpose refer to the office of the county surveyors, who can indicate the district surveyors and their areas.

N.B.—In some cases the same road is maintained by more than one body along different sections ; some by contract, others administratively.

2. Pass over the entire length of roads included within the whole area with them about 14 days before the troops begin to assemble, and make general notes by enquiry at farms, counting carts, etc., etc. The hire of a motor car for this purpose is essential.

3. Classify roads of all kinds (private and public) under four or six heads, according to the actual *condition* of their *surface*, and without reference to their breadth. Where the roads are in a bad state, the attention of the local authority should be drawn to their condition, and an agreement come to regarding the classification *before* manœuvres commence.

4. The following classification recorded by distinctive colours on the map is recommended :—

	Good	Fair.	Bad.
Metalled	Dark blue.	Crimson.	Black.
Unmetalled ..	Violet.	Scarlet.	Brown.
Gravel	Light blue.	Pink.	Yellow.
Grass	Light green.	—	Dark green.

5. During manœuvres take note, as far as possible, of what military traffic passes over each road per diem.

6. Immediately after manœuvres—

(i.). Write to all surveyors, asking them to inspect their roads and notify the places for which they propose to claim, and the amounts.

N.B.—Some difficulty may be experienced in getting claims sent in unless an ultimate date is given.

(ii.). Make appointments with claimants, and re-traverse the roads in question.

7. The War Office will only pay for damage done by "*extraordinary*" military traffic ; the mere marching of troops and the passage of vehicles to and fro, on arrival at and departure from the manœuvre area, should not be included under the term "extraordinary."

The troops are entitled to use public roads as citizens and individuals.

8. The War Office is *not* bound by the by-laws of local road authorities. Where the Manœuvre Act is not in force the claimants in a disputed case must either sue the W.D. or come to some agreement with the Road Compensation Officer ; the latter is preferable for all parties.

9. Repairs should be postponed till after manœuvres. If the local authority is insistent on immediate repairs, the road must be carefully inspected and condition noted at once. Further compensation should be refused, as fresh metal, newly laid, will not consolidate under traffic ; it is bad practice.

10. If the weather during manœuvres be dry, some roads, especially gravel and flint metalled, will break up rapidly under animal traffic, and appear more heavily damaged than is really the case. Assessment of damage should be postponed till after some falls of rain, as this will consolidate the surface very quickly.

11. Horses' hoofs do more damage than *ordinary* wheeled traffic; therefore pay close attention to roads used by mounted units, and make repeated visits.

12. Resist all claims for extensive renewals, *i.e.*, grants for new metalling, and give way on scarifying, steam rolling, watering, etc. The cost of new metal soon totals to a large sum.

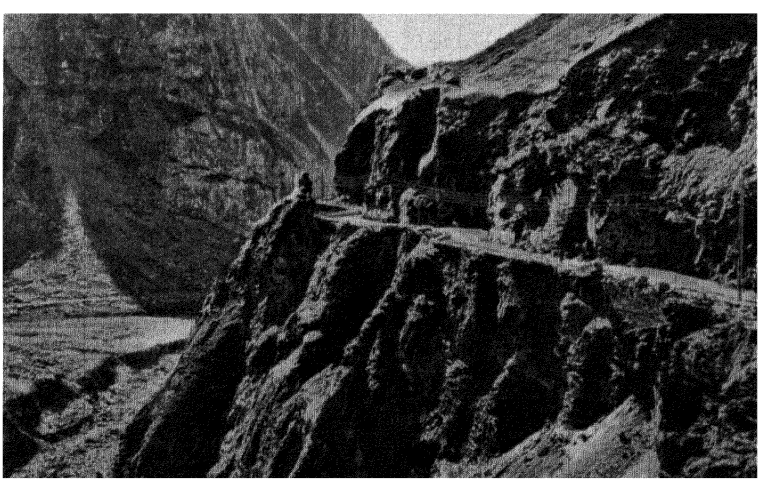
N.B.—It has been ascertained experimentally that it takes more traffic to wear down a road surface ¼ inch than is at all probable during the average duration of ordinary peace manœuvres.

13. Private road owners may make unreasonable demands; therefore be on the lookout for weeds, etc., growing on the road surface, which are a good indication of the infrequency of ordinary traffic.

14. Any agreement come to will probably have to be based on a mileage rate at what the repairs *will* cost, and not *have* cost.

15. Obtain a record of local prices and labour rates, and collect all available data as to actual cost of all kinds of road work generally.

16. Use a manifold letter writer, so as to keep a *complete record* of all correspondence; this may prove invaluable as a reference in case of litigation or dispute.



A Precipice Cart Road.

CHAPTER II.

Military Roads in New Countries, Roads during Military Operations, etc.

Military Roads in New Countries.—The broad principles are the same as already enumerated, but the application is often altered by circumstances, *e.g.*, in hill and mountain roads the gradient nearly always rules; next come obligatory points, such as bridge sites, economy and limiting amount of earthwork, etc.; again, where land can be acquired for almost nothing to make roads across open country, the width of the road metalling is limited more by the cost of maintenance than by traffic.

In India, United Provinces, and the Punjab it is not uncommon for first-class roads to take up a width of over 100 feet, assuming the road to be on a 2-foot embankment, so as to be above the level of floods.

The width may appear excessive, but as land is invariably cheap in new countries, a greater width will admit of the planting of avenues of trees, which in time will provide shade and protection to caravans, and also allow of separate tracts for slow and fast traffic (see p. 39).

In such cases the earth is obtained from "*borrow pits*" at the side. These should not be continuous, but separated by earthen partitions left natural; they may be connected by pipes.

The cross section (*Fig.* 23) shows the kind of road aligned for many miles in parts of India. The unmetalled portions, 15 feet wide, between the pit and the bank are used by bullock carts,

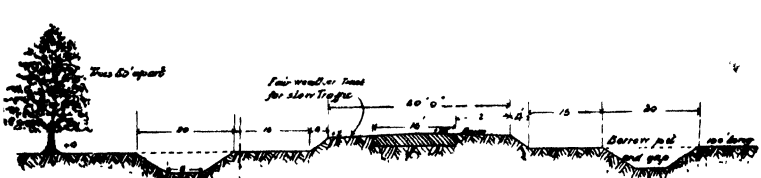


FIG. 23.—*Cross Section of Grand Trunk Road, India. 1,500 Miles, Calcutta to Peshawar.*

strings of which pass along slowly night and day. Even shod bullocks soon suffer in their feet on metalled roads. The central metalled portion is for rapid traffic. The banks should be allowed one season to settle before metalling. In forming embankments the earth layers should slope inwards; if convex, the bank will tend to slide (*Figs.* 24 and 25).



FIG. 24.—*Embankment formed Correctly.*



FIG. 25.—*Embankment formed Incorrectly.*

In Central India and Bombay roads are not so extensive—about 72 feet, including the "kutcha" part.

In "black cotton soil" thorough drainage is of first importance; a coating of sand (6 inches) should always be laid on an embanked or road bed surface, whether to be metalled or not.

EARTHEN ROADS.—By earthen, or natural soil roads ("kutcha," India) is meant those formed entirely of clay, sand, and gravel and sand, and the ordinary earths.

In tropical Africa the majority of the roads are formed of earth; their surface bakes very hard and gets well consolidated from the traffic of thousands of natives passing over it barefoot; there is no wheeled traffic to cut them up.

To form earth roads:—

Remove all mud, perishable and loose material.

Roll and compact surface, and break up all lumps.

Provide ample drainage and keep surface exposed to wind and sun.

Cover with a layer of 3 inches to 5 inches sand, gravel, shells, cinders, furnace slag, or broken burnt clay, and consolidate well.

Surface to be well barrelled to throw off rain, or in the hills inclined inwards.

In the hills the outer edge to be banked up from excavation to form a parapet.

Streams crossed to be taken over the road by causeways or in culverts, according as they are intermittent or perennial.

Gravelly soils on either a sandy or clay foundation make good roads—provided the foundation is previously well rolled and "crowned" (1 in 20).

Each layer should be uniform and not exceed 3 or 4 inches in thickness; be spread carefully and consolidated separately, otherwise a compact surface overlaying loose layers below will result.

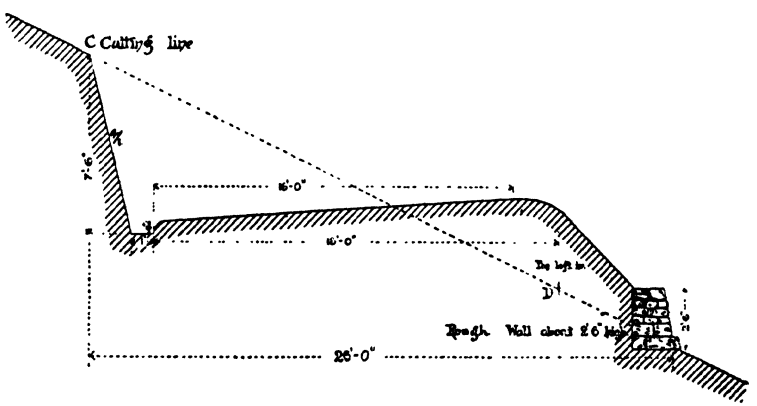


FIG. 26.—*Earth Road, Tropical Africa. Cross Section on Steep Hillside.*

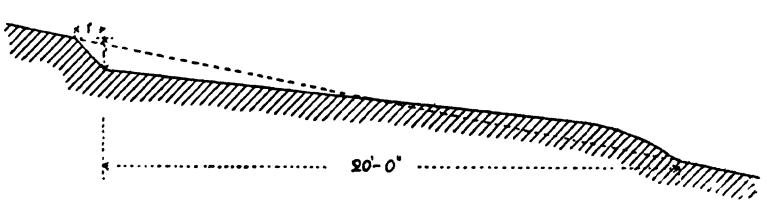


FIG. 27.—*Earth Road, Tropical Africa Cross Section on Slightly Sloping Ground.*

In Burma a top dressing of sand has been used to make an otherwise muddy road passable in the rains. The effect is much the

same as that observable on the sea beach when the tide has receded and the sand is wet and hard.

In maintaining earth roads, neither ruts nor holes should ever be filled with sods or turf, as they rot and cause mud; nor should they be filled with broken stone, else hard ridges and uneven wear will result.

When an earthen road is much cut up with ruts and mud, the simplest method of reclaiming it, and restoring the contour and surface, is by going over it with a "split-log scraper," drawn by a team of horses. The scraper or drag is made from the two halves of a 10-foot log, about 10 or 12 inches in thickness, set on edge about 2½ to 3 feet apart, and kept in position by three hard wood bars tenoned into the split logs. A plank is nailed to these close up to the back of one log for the driver to stand on. A pair of animals or a team is hitched to a chain fastened to within 1½ feet of the ends of the front split log, and in such a way that the drag will run at an angle of about 40° to 45° with the direction of the road. As it advances, taking one-half of the road width at a time, the drag levels down the ruts and moves the surface earth towards the centre of the road, as well as acting as a mud scraper. In course of time the surface will harden, as it gets cleaned more frequently and dries quicker than if left coated with mud and full of ruts.

Road-Constructing Machinery. — American practice is very much in advance of English practice in the methods of preparing the "subgrade" (*i.e.*, the formation surface level or bed) upon which a road foundation is laid.

For small jobs the wheelbarrow and "dobbin cart" for long past have been superseded by some form of "drag scraper," drawn by a horse, which moves the soil after it has been turned up by a plough. (For comparison and cost see *Trautwine's Pocket-Book*, p. 747).

There are various kinds (*Figs.* 28 to 33)—Drag scoop, tongue scraper, buck scraper, wheel scraper.

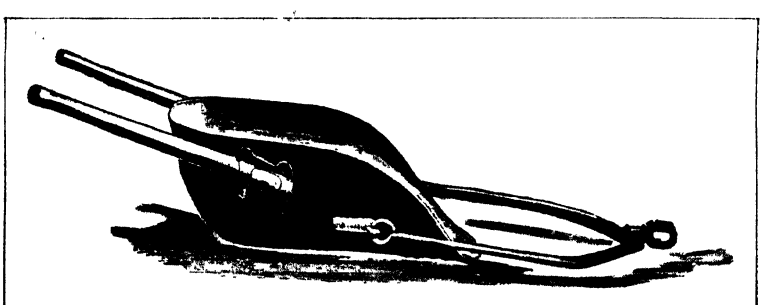


Fig. 28. – *Drag Scoop Scraper.*

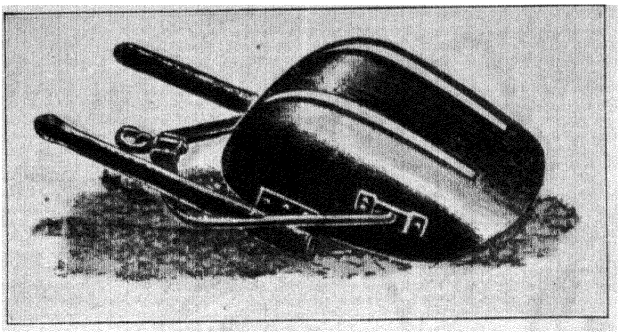


FIG. 29.—*Drag Scoop Scraper.*

Nowadays it is found that subgrades, both for roads and railways, can be much more expeditiously, cheaply, and better prepared by special machines called "Road Scraping or Elevating Graders."

The *Scoop* and *Tongue Scraper*, 36 and 38 inches wide, cost from 25s. to 30s.

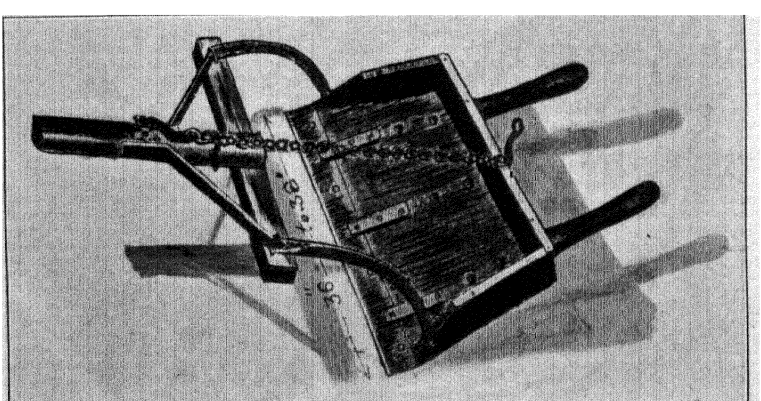


FIG. 30.—*Tongue Scraper.*

The *Buck Scraper* runs 3½, 4, and 5 feet wide, with capacities of 8, 10, and 12 cubic feet, and has a prime cost between £4 and £5, according to size.

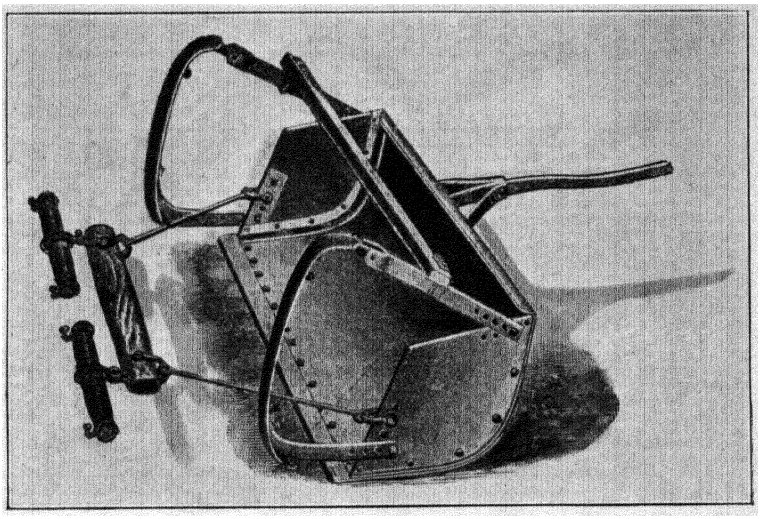


FIG. 31.—*Buck Scraper, ready for Loading.*

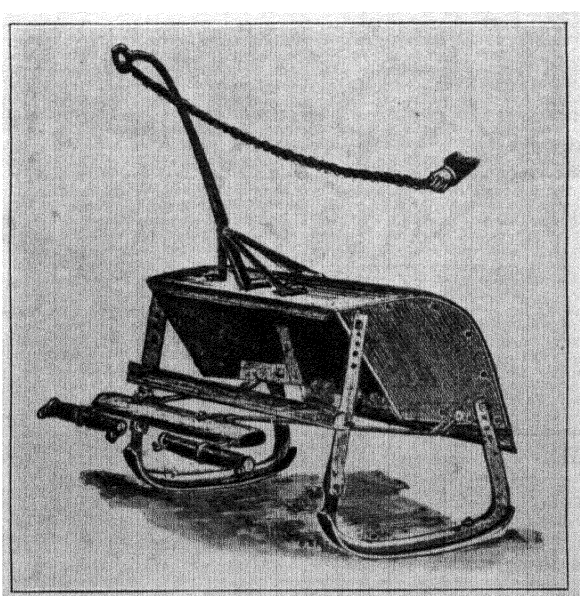


FIG. 32.—*Buck Scraper, Dumped.*

The *Wheel Scraper* is made in three sizes, having a capacity of 9, 12, and 16 cubic feet respectively, corresponding cost between £6 and £8.

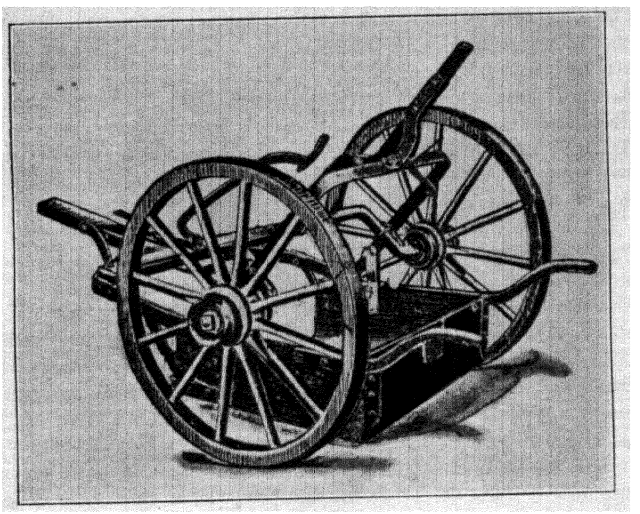


FIG. 33.—*Wheel Scraper, Filling.*

A *Scraping Grader* costs from £48 to £50, and requires four to six horses or a traction engine to draw it ; it can be operated by one man.

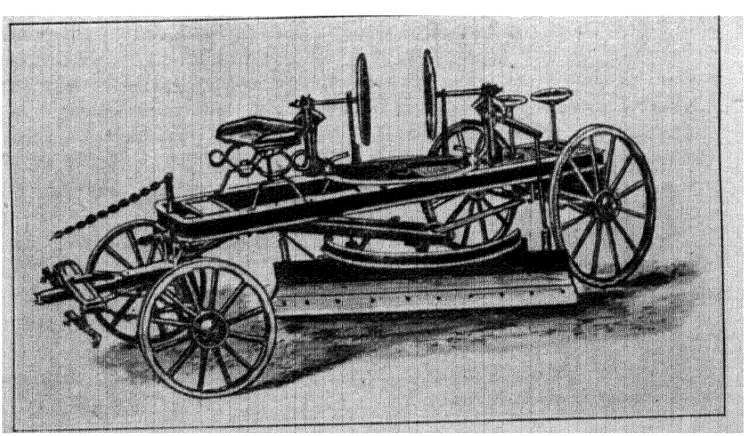


FIG. 34.—*Champion Scraping Grader.*

The cost of building an ordinary prairie road 30 to 35 feet wide in the States with this machine amounts to £6 to £9 per mile.

Scraping grader work in prairie soil usually costs from 1d. to 1½d. per cubic yard.

The *Elevating Grader* is specially adapted to constructing prairie roads and earth banks, or filling wagons; it can be drawn by horse or steam traction.

A small machine will grade a quarter mile of prairie road 25 to 30 feet wide in one day.

A large machine will place 1,000 cubic yards of earth in an embankment, or load 600 cubic yards into wagons in 10 hours, under 3d. a cubic yard.*

PROSPECTING, *Plains.*—In prospecting for a road in a flat country it is natural to seek to align it as direct as possible.

Consult the Civil and Irrigation Authorities where they exist as to what arrangements are required as regards traffic, and for passing irrigation water across the proposed road; if this is not done in the first instance unforeseen extras, *e.g.*, culverts and waterways, may be found necessary, with a corresponding increase in the estimated cost.

It is desirable, however, to consider proximity to quarries for metal, claims of traffic from neighbouring villages and towns, diverting the alignment in their direction for the purpose, if need be. The extra length caused thereby will probably not add much to the cost, and may be a great boon to more than one community.

Native towns are of less importance, as a rule, than European cantonments and military garrisons; hence *direct* routes between the latter will claim preference, and may cause the route to skirt native centres, to which branch roads can be constructed later.

Rest houses can be built on the main route, where water is obtainable; in a short time an enterprising native community will create a "bazaar" near a frequented rest house, and the native village will extend in that direction. By relegating the bazaar and natives to a "reserve" *selected beforehand*, clear of the rest house, there is less chance of the water supply being polluted, and considerable inconvenience to travellers may be saved in future. To camp beside a main route which passes through a native centre has obvious disadvantages as regards sanitation and otherwise.

The monotony of a perfectly straight road should be broken; this may be done, failing natural deviation, by introducing a curve, and planting trees, digging wells, etc, to hide it, lest the curve be interpreted as a makeshift or error through faulty alignment Apart from this, shade and water are acceptable in hot climates.

A special grant of money is made in India for the planting of trees along roads and canals.

* Baker—*Roads and Pavements*, 1903, Chapter 3.

ROAD SURVEY.—The following procedure is recommended for carrying out road survey work in :—

(*a*). Undulating and hill country covered with jungle, *e.g.*, Chin Hills, Burma, tropical Africa, and India, etc.

(*b*). Mountainous tracts devoid of vegetation, *e.g.*, the Indo-Afghan frontier and higher Himalayas, etc.

All preliminaries regarding detailing of survey parties, and staff, transport, camp equipment, tools and plant, surveying instruments, rations, collection of labour gangs, method of payment, and, if necessary, military escort, hospital and medical arrangements, must be carefully thought out beforehand at the base, before any field-work is started. Meantime available maps should be consulted and studied.

(*a*). *Undulating and Hill Country.*—1. If a reliable map of the country exists (say, 4 miles equals 1 inch), the line of the proposed road may be approximately located.

2. The field engineer and assistants make, traverse, and prospect the proposed line and adjacent country; if time permits, make a rough plane-table survey, or some kind of preliminary reconnaissance, taking a series of "flying levels" careful aneroid barometer readings* of all "ruling" (obligatory) and important points, such as heights of saddles, passes, villages, railway and river crossings and junctions, irrigation passages, bridge sites, etc., watersheds, marshes, and low ground; isolated hills, landmarks, escarpments, natural gradients and slopes, wells and water holes, perennial streams, attitude of natives, labour market and supplies, building materials available, etc., etc. Highest flood levels should be recorded after careful enquiry and close observation of their effects and traces on the route.

3. Divide up the line into sections, and allot to survey parties in charge of a responsible subordinate.

4. A tracing party pegs out the line by eye, using a De Lisle clinometer, or can blaze trees and cut a line in the jungle. A theodolite takes too long. In tall elephant grass use a high-step ladder.

5. Labour gangs follow and cut a path 1 ft. 6 ins. or 2 feet wide along the final pegged alignment.

6. Make a finished plane-table survey and longitudinal section where required, with cross sections at intervals, noting nature of soil, rock, jungle, drainage lines, sites for waterways, culverts and bridges in a fieldbook.

The results of *each day's work should be plotted without delay* at night, if necessary, and levels of the important points above mentioned carefully preserved in a *second* book, in case of accidental loss, crossing a river, etc.

* Watkin's pattern (3¼ inches), by Hicks, Hatton Garden, is recommended.

When a river crossing to be bridged exceeds 15 feet span, a longitudinal section of the river bed, and two cross sections half a mile above and below, should be taken, whence requisite data for computing the waterway can be obtained.

In any case a reconnaissance of the *district* should be made, not merely what appears a suitable line, the whole length being completed before work is commenced on the road. Doubtful and alternative routes should be sketched and recorded.

On the return journey improved alignment can doubtless be selected, which may necessitate additional survey, cross sections, and sketches.

7. Prepare plans, estimates, and report, duplicating, where desirable, for future reference.

N.B.—It will be of assistance to peruse reports and notes of previous road surveys in the same country, if possible.



(*b*). *Mountainous Tracts.*—Where a road has to be in mountainous country, as in the Himalayas, it is usually carried above the valley slopes, at some height above the rivers and beyond flood level.

The general procedure is much the same, except that it may be desirable to run a *careful traverse* line as a basis for all work,

including the river, contouring roughly from the water's edge to 100 feet above the traverse.

Permanent bench marks should be cut on well-built massive masonry pillars or on existing large rock surfaces every half mile for the guidance of following parties, to indicate points on the route and important changes of direction and gradient.

The traverse can be made with a theodolite or a 6-inch prismatic compass on tripod stand; the latter is more portable where cliffs have to be negotiated; it saves time, as long shots are seldom possible.

For chaining a steel tape* is preferable; a 12-foot horizontal staff, with a spirit level, and vertical ranging rods, with plumb bob or spirit level attachment, are useful where chaining up and down very steep slopes.

If contours are required, points on the valley slopes can be determined by using a plane table, upon which the traverse is plotted for taking rays up and down hill.

Set up an Abney's level (set at zero) on a 5-foot rod, siting anywhere on the hillside, along the rays; points on the hillside can be found 5 feet above the trace, and plotted by measuring the *horizontal* distance; this may be effected more rapidly by using the 12-foot horizontal rod.

On regular hillsides the ordinary method of taking slopes with a clinometer and plotting the horizontal distances of the contours is sufficiently accurate.

In putting a pencil line on to a contoured plan it is a help to mark the "grade contour" or line where the plane of the grade strikes the natural ground surface.

In general it is better to select a route which can be opened at small cost and improved later, as funds admit.

Time devoted to careful location is well spent.

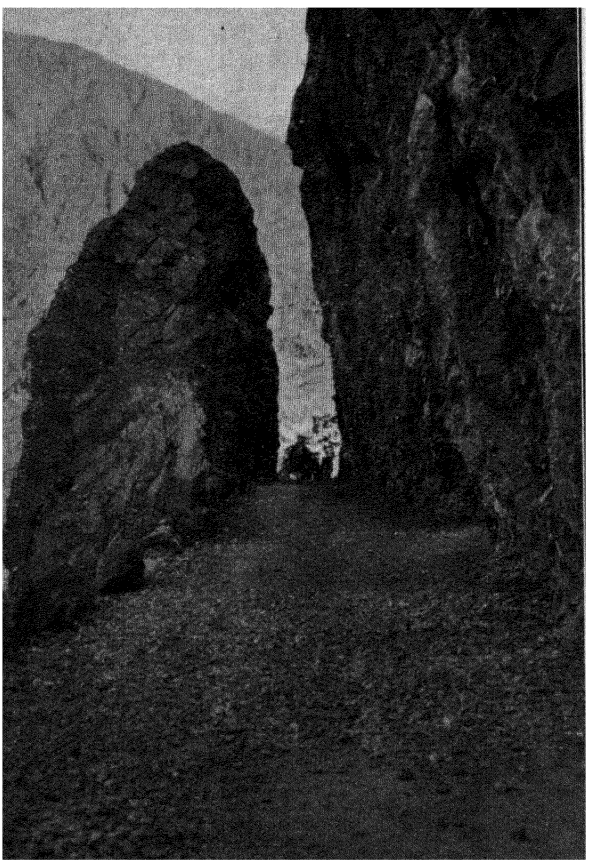
In roadmaking, more than in anything else, "more haste means less speed," and it may also be added "incalculable expense."

The best line for a mountain road is that in which the total sum of the ascents and of the descents between extreme points is the least. It should always be remembered that length to overcome height is the one thing sought for; every possible foot of rise gained should be maintained and never lost.

In this manner it is possible to select a probable alignment which, when afterwards surveyed in detail, will not be far out. In selecting a probable route native tracks are useful, but not always reliable,

* J. Halden & Co., Albert Square, Manchester; Lufkin Rule Co., 24, Holborn, London, and Saginaw, Mich., U.S.A., or Chesterfield & Co., London.

and, therefore, should not be accepted as necessarily the best. For instance, the track may avoid some precipice or obstacle, which, although insurmountable by foot traffic, may not be so to engineering skill (see *Plate* I.). At the same time native tracks should be examined and utilized as a base for surveying and observations. In



A 45-ft. Through Cutting in Hard Shale.

wooded countries they are invaluable, and usually safe to follow as a guide. In thick jungle and in the hills they are unreliable ; as a rule the trend of native tracks is determined by camping and pasture grounds, which must receive considerations in the selection of routes.

The straightest alignment is not necessarily the nearest in hilly country. The expense of deep cuttings should only be incurred when the total rise can be reduced thereby, and there is ample time, thus :—

Take two points, A, B, with a hill intervening, but whose base can be traversed. The length A to B, over the top A, D, B, equals the distance A, C, B, round the base, but the loss in power exerted, so as to rise from A to D, is obviated by the detour on the level ; hence it is permissible—as a working rule—to increase the length 20 times the height saved by detour, *e.g.*, a 2,000-foot detour of extra length is allowable to avoid a hill 100 feet in height.

Traffic is hindered less by an extra mile of good road than by a few hundred yards of bad.

Where a road has to be made in the hills, consisting of low ranges and cultivated valleys, it is best to avoid the low ground and *skirt the high ground* of the valley slopes where the ground is drier ; by this means, besides getting a better foundation in all probability for bridges and culverts, the water courses can be crossed higher up nearer their source by a series of small culverts and drainage openings, instead of where these small streams have united to form a river, which would require a bridge, often entailing troublesome foundations and embanked approaches. In other words, aim at working along watersheds ; it may take longer and be more difficult to construct, but a better road will be secured and the cost of subsequent maintenance will be small.

There are other important matters which influence the selection of a route, whether on one side of a valley or the other, viz. (see *Figs.* 35 to 38) :—

(1). Dip of strata, whether towards or away from face of hill ; occurrence of faults.

(2). Whether acted upon by sun or sheltered, for action of sun is relied upon for melting snow, which, if collected in drifts on a sheltered road, may lie several months as a bar to traffic.

(3). Whether the strata quarried in cutting the road will provide good blocks and slabs for masonry work—culverts, retaining and revetment walls, etc.

In the Himalayas northern slopes are often thickly wooded, where southern slopes are bare. As a rule, the wooded side should be selected, notwithstanding the increased labour of tracing and clearing, because trees break the force of rainfall, and the mould beneath the trees passes it off gently over the road, which might, in a bare hillside, be cut away by an unchecked rush of water ; on the other hand, the wooded portion has a greater depth of soft soil and roots, which are a disadvantage.

In laying out a road with many bridges, select the bridge sites first, and lay out the centre line of the bridge before fixing the direction of the approaches.

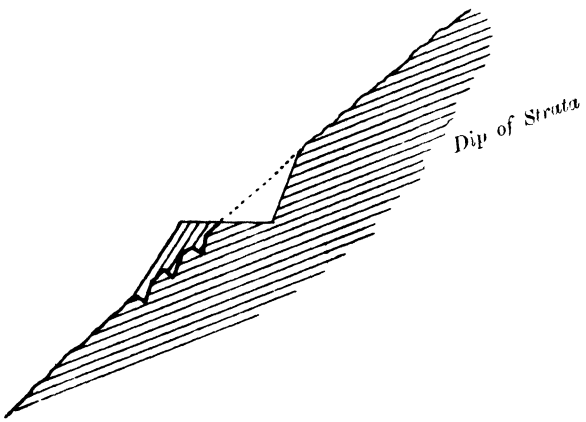


FIG. 35.—*Road Unsafe (Strata Shelving).*

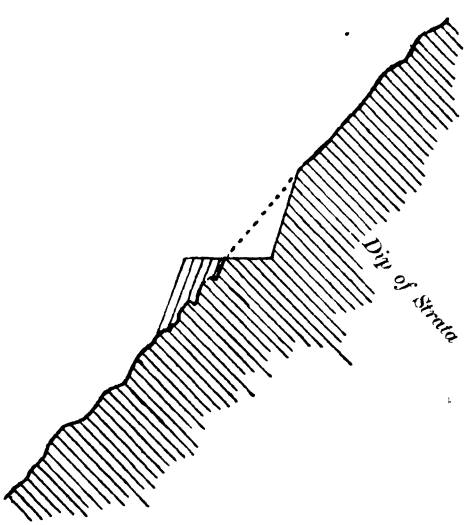


FIG. 36.—*Road Safe.*

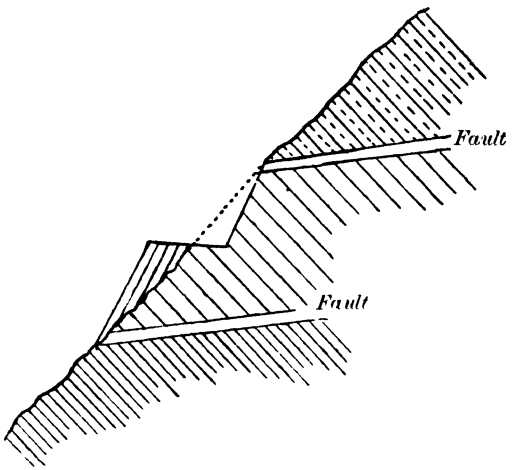


FIG. 37.—*Stratification Favourable, but Road Unsafe on Account of Faults.*

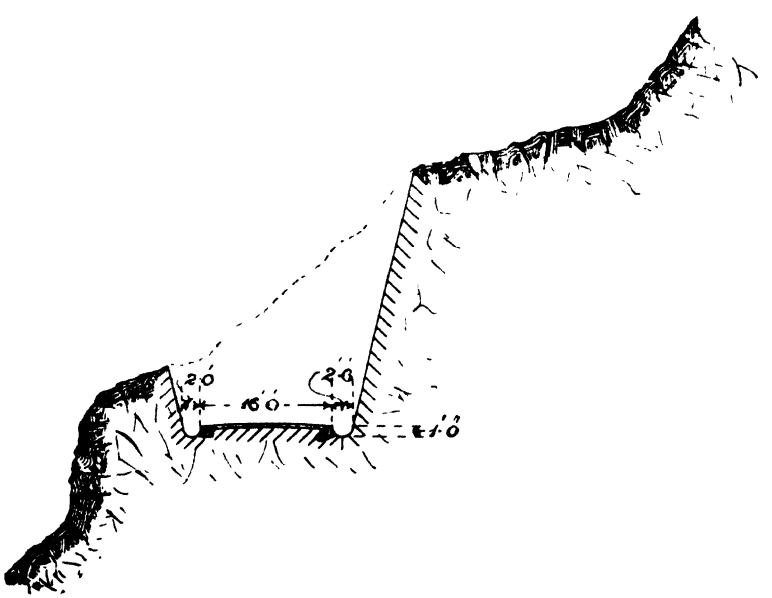


FIG. 38.—*Mountain Road, Cutting Section.*

TRACING.—The De Lisle clinometer is the best portable instrument for laying out *grades;* Abney's level for obtaining *level* lines along precipices and sidelong ground. In lining out a hill road with steep gradients, commence from the top, *e.g.*, at a pass, if possible, as hills and mountains being steeper towards the summit, there is far less choice of line than lower down. If the gradient trace is commenced at the foot slopes, there is no guarantee that a given pass in the watershed can be reached without resorting to zigzags, which ought to be considered inadmissible. Therefore traverse *down from "neks"* and *up from bridge sites.* Note by eye points up hillsides, especially at salients, which the maximum grade line will cut; the road will then not exceed the maximum grade.

If laying out along the ins and outs in sidelong ground by forward shots, it must be borne in mind that the original trace of curve must be laid out a good deal easier than the gradient intended for the road when completed. The allowance to be made varies with the nature of the ground; in general, 1 in 37 will work down to 1 in 35, and 1 in 22 to 1 in 20. It is a sound plan in laying out to conform to surface gradients as far as possible. In tracing over rock, line out with whitewash and red paint; make the bench marks very distinct, so as to be easily identified.

In wooded country "blaze" the trees, *i.e.*, cut marks; in dense wood, or in tall elephant grass, use flags and smoke to align upon, and take observations from the highest trees; or, better still, portable high-step ladders.

The trace should be laid out, when there is ample time, with *regular curves and straights* if possible; it looks better and is easier in the long run; the grade should be eased on curves.

Where reverse or S curves occur—and such are common—they should be connected by a piece of straight; similarly where two curves of different radii occur, trending in the same direction

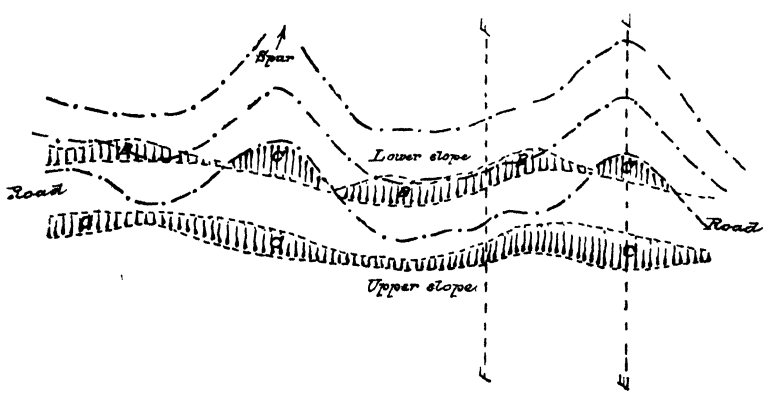


FIG. 39.—*Road Tracing, keeping Inner Edge above the Contour.*

they should not run one into the other, but be separated by a straight length. They are then simpler to lay out, and in case any deviation is necessary, the straight piece affords a margin to bring their springings nearer, if need be; but this applies more to railway work.

In following a contour, the inner edge of the road should be kept above the contour, to avoid holding up water or putting in a culvert (see *Figs.* 39—41).

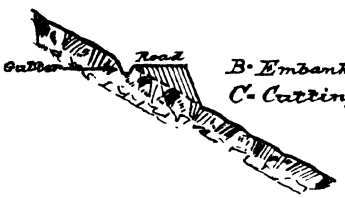


FIG. 40.—*Section at F.F.*



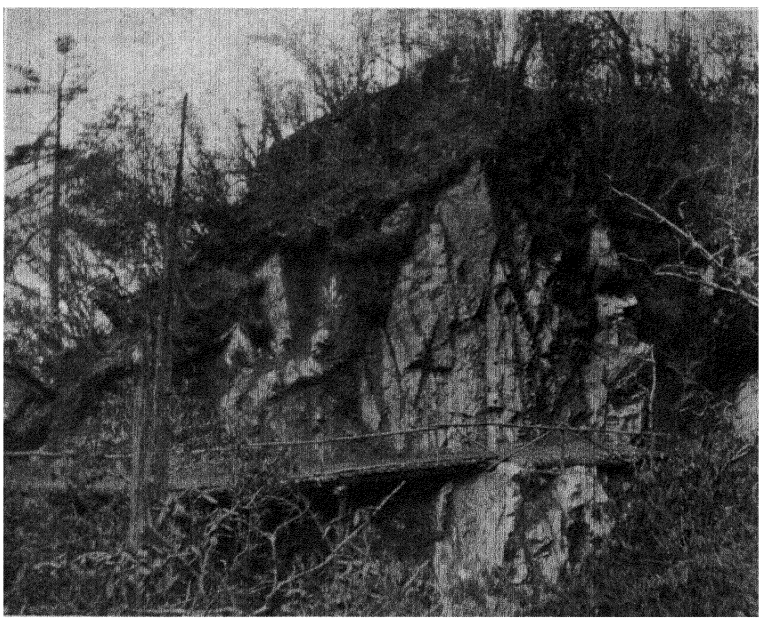
FIG. 41.—*Section at E.E.*

CONSTRUCTION.—No road should ever be commenced until the trace is cut throughout; it is often tempting to disregard this when time presses, but to do so is not sound practice. The great thing is to get a 4 foot path, or even a *one*-foot path, right through as soon as possible; this can be widened to 6 feet, 8 feet, or more, according to requirements (see pp. 6, 55, 86).

In opening the first 4-foot track, where very difficult cliffs occur in the line, temporary tracks may be made either above or below the proper level, as the nature of the case may permit, taking care after passing the obstacle immediately to regain the proper level. By this means an immediate passage can be obtained long before the permanent route, could be made in its proper position. And it is desirable that such temporary passages should be *above* rather than below the proper level, because, in that case, the progress of the permanent route, in its proper position along the cliff, will not be impeded by persons passing over the temporary track. The width of these temporary tracks should be suitable for the passage of mules, and they may, in many cases, be made to occupy either the brow of the cliff, which will ultimately be worked down to the road level, or the foundation of a wall, to be subsequently built up to that level.

In actually cutting the alignment, start with a narrow path and peg out every 100 yards, or less, if desirable, one peg in the *middle* of the road (finished breadth) if possible, and one at the side, to enable this to be found; the centre one should be put in below the ground level and covered over. Spit lock the boundaries on level ground; in sidelong ground mark the *outer* cutting line only, and work inwards, not down, from the cutting line on the hill slope. Keep a careful check on level pegs, and replace with supplementary mark as soon as they have to be moved.

Cutting lines should be laid out at least one day in advance of the construction party, so as to avoid confusion, mistakes, and delay in commencing the day's work.



Cliff Work—A Temporary Track.—Tibet.

A width of 4 feet should be cut into the hillside for the whole length; each section can then be widened. In sidelong ground, where the road is wholly in bank, the foundation for the retaining walls should be got out with care and built as soon as possible.

A useful series of sections for mountain roads in rock and various soils is given in *Figs.* 42–49.

Where the hillside is of gentle slope, half of the road may be carried on blasted debris, with careful rough building up.

The tasks can then be set as follows.—Each headman, or ganger, is given a certain number of yards run along the route, according to the number of men in each gang or party. The length per man will vary from 1 yard on very steep, hard, or difficult ground to 8 or 10 yards on easy level stretches. A couple of weeks' experience will soon indicate to the engineer in charge what is a fair allotment. Thus on the same day one gang may have 3 yards per man, another 4 yards, and so on (see also p. 116).

Each gang should be required to complete the allotted task, collect and return stores, tools, etc., before being dismissed.

All the stumps, obstacles, and small stones must be removed; boulders too massive to shift are left to be blasted by trained men. Before doing so the road gang must clear out the earth from around the boulders, below the surface, so as to ensure an effective blast (see p. 83).

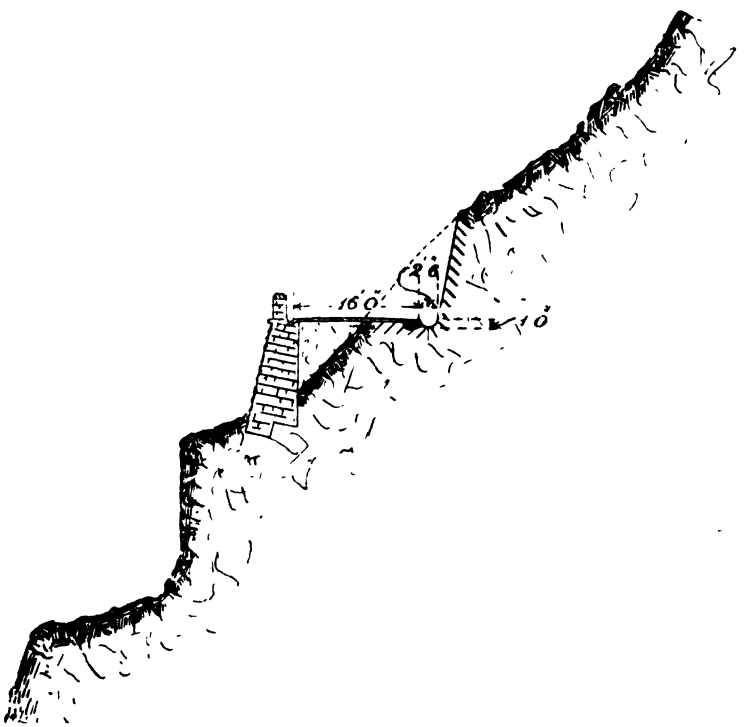


FIG. 42.—*Mountain Road, Section in Sidelong Ground.*

It is well to remember that very few natives have an eye for a straight line, nor do they appreciate the necessity of accurate alignment; therefore all tasks must be properly laid out with tracing lines and pegs beforehand.

During progress of the work levels must be frequently checked, as roadmen have no hesitation in obliterating marks less easily detected, and putting fresh marks of their own in more convenient places to work in.

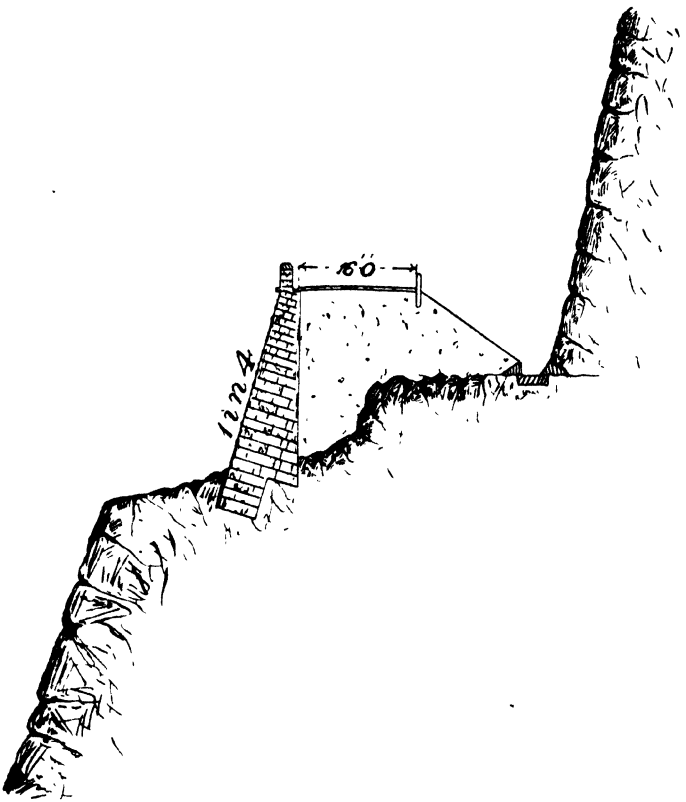


FIG. 43.—*Mountain Road, Embanked Section.*

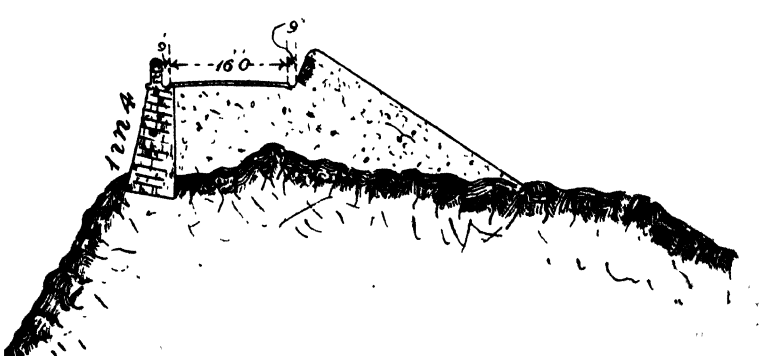


FIG. 44.—*Mountain Road, Saddle Section.*

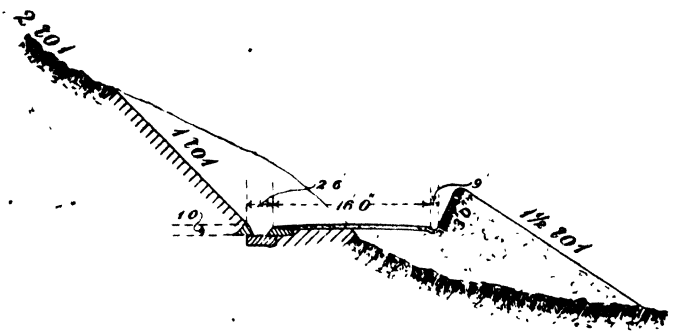


FIG. 45.—*Mountain Road Section in Soft Soil for Slopes from level to 2 to 1.*

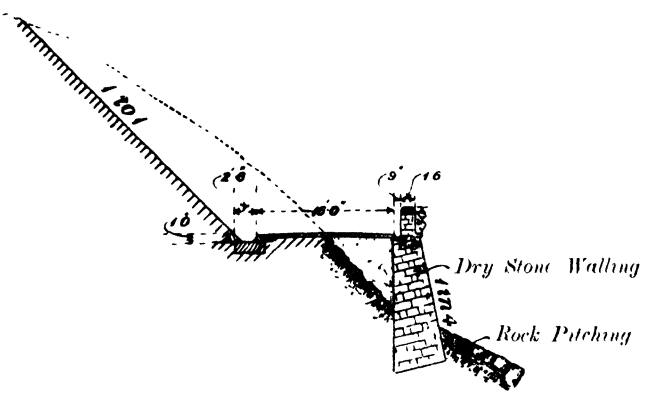


FIG. 46.—*Mountain Road Section in Soft Soil for Slopes from 2 to 1 to 1½ to 1.*

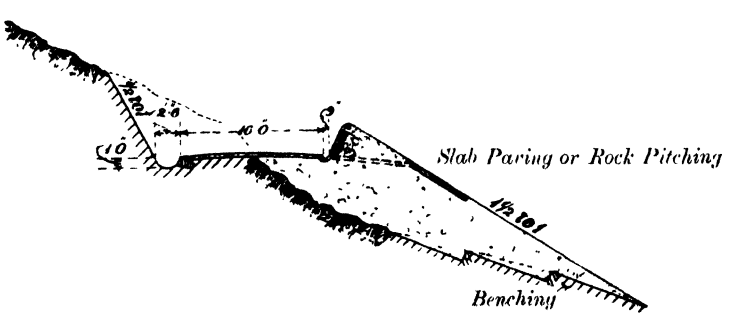


FIG. 47.—*Mountain Road Section in Hard Soil for Slopes from level to 2 to 1.*

The importance of level pegs also is usually not appreciated by the road contractor's labourer. In India a useful deterrent to prevent removal of pegs is to place a "chattie" (earthenware pot) over every peg, whitewash it, and take a receipt from the ganger or contractor as each is put down; then fine him a rupee for each peg missing or moved.

A most important point to remember is *never to cut below* the level given to work to.

A road can be cut down if need be, but filling and making up is permanently unsatisfactory.

In sidelong ground the embanked portion should have a steeper inward slope than the part in cutting, so as to allow for settlement.

No earthwork is sufficiently consolidated for completing the surface and drains in tropical countries under two rainy seasons.

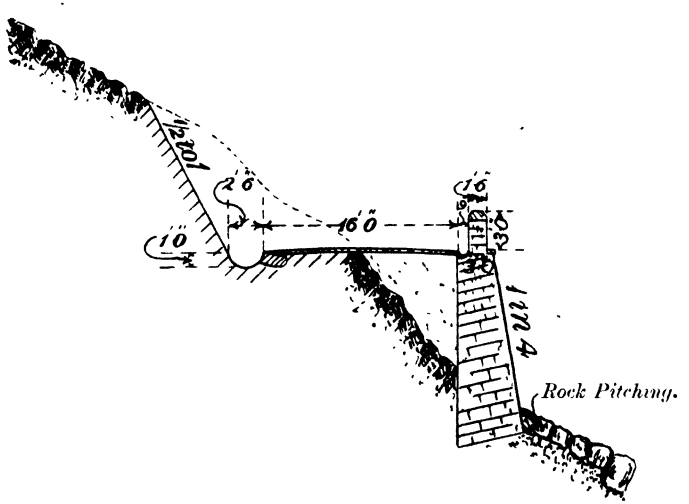


FIG. 48.—*Mountain Road Section in Hard Soil for Slopes from 2 to 1 to 1½ to 1.*

Sides of banks and cuttings when settled should be turfed, pitched, or sown with grass seed—American grass seed preferred—scattered over the surface, which may be prepared beforehand with a mud and cow-dung plaster.

In *metalling*, lay the stone along the probable line a driver will take, *i.e.*, clipping corners not necessarily equally on either side of the centre line of roadway; in any case a greater breadth of metal is required at curves than on the straight.

Moraines.—Where these cross a road alignment, the best arrangement is to leave their surface untouched and build up over them,

without attempting to remove enormous boulders, which frequently lie on their surface; to cut through a moraine is risky and creates a danger spot.

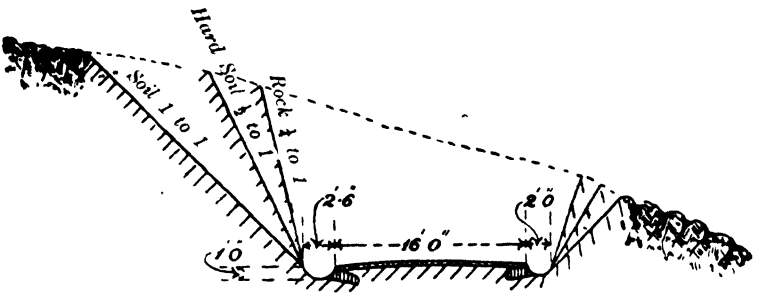


FIG. 49.—*Mountain Road Section in Cutting, Slopes for various Soils.*

GRADIENTS.—The maximum gradients that are generally admissible on metalled or good unmetalled roads are:—

1 in 25 for wheel traffic, with continuous ascents exceeding 5 miles.
1 in 20 for wheel traffic in general.
1 in 17 is practicable for a cart road.
1 in 16 for laden camels and mule carts.
1 in 10 for pack horses.
1 in 8 for mules.
1 in 5 for foot traffic.
1 in 4 for a mule *path* is practicable, but wearing and most fatiguing.

Ease where possible.

Camels soon fail on continuous steep grades; oxen, on the contrary, pull well on long steep slopes.

A Table of grades per mile is given as Appendix A; see also *Molesworth's Pocket-Book* (1905, p. 240), *Trautwine*, p. 723, and *Roorkee Treatise*, Vol. II., p. 220.

A continuous rise at the maximum gradient for more than 600 yards should be avoided by breaks with stretches of level or very flat grades; such stretches may be but small, 40 or 50 yards, or less; they not only ease animals, but break drainage and prevent accumulation of water, which would otherwise scour the surface. It is better to cross precipices and difficult places on the level, if possible.

In approaching "drifts" short lengths at 1 in 10 or 12 are often unavoidable, but they should always be straight.

The *average* grade on any hill road should be much less than the above :—

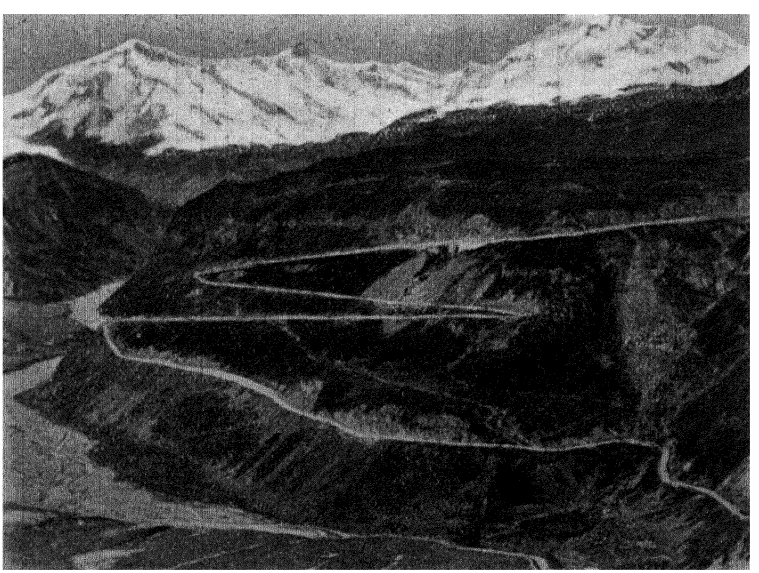
1 in 50 for cart traffic.
1 in 20 for camels.
1 in 15 for pack animals.
1 in 8 for foot traffic.

The Simla-Kalka cart road rises 7,000 feet in 56 miles, giving an average grade of 1 in 42. The ruling grade is 1 in 20.

The Amba-Ghât Road (Western India), 20 feet clear width, has an average grade of 1 in 23·2, with a limiting grade of 1 in 20; minimum curve, 80-foot radius.

The Tonga Road, between Rawal Pindi and Murree, and beyond, in many places has grades as steep as 1 in 10, but the strain on animals is excessive. (N.B.—A "tonga" is a low two-wheeled cart for a pair of ponies).

Zigzags.—It often happens that in crossing a watershed in a mountain range the opposite sides present very different conditions, a gradual rise on one side often leading to a precipitous descent on the other: in such a case the road must be doubled upon the spurs



A Precipitous Descent—9 Miles at 1 in 20

or zigzags formed. In either case the plan to be adopted is to select suitable spots for turning places, and then connect these obligatory points by the easiest surface grades possible.

The character of the valleys of approach must determine the system of gradients to be adopted. If a river emerges in a cañon, some system of zigzags will be necessary to get from the head of the pass to the bottom of the valley, which the road must then follow to the end of the cañon.

The Georgian Military Road from Vladikavkaz to Tiflis, in the Caucasus, presents features of this character.

Zigzags are undesirable in any alignment except for foot traffic, or in a special case where it is necessary to keep the road under the protective fire of some commanding post or fort, which could not otherwise be effected.

Zigzags seldom advance progress to destination; height is surmounted, but horizontal distance is not overcome. If the drainage cannot be carried clear of the road at the end of each "reach," it must be taken under each reach by a succession of culverts until it can be carried clear. They are most dangerous, and accidents, with loss of life, both to men and animals, frequently result.

Even if no such disaster occurs from a runaway cart or fractious beast, they invariably cause *hopeless blocks*, especially where strings of bullock carts meet at the angle.

Sharp curves are to be avoided; 45 feet is a minimum radius, and the roadway should be widened at curves.

Where guns are to be transported, the roadway must be wider at re-entering angles (to allow for the increased track of trail and limber), and the gradient should be increased for, say, 100 yards to more than 1 in 20, if thereby a zigzag can be avoided.

To estimate the amount of widening when the radius of curvature is under 200 feet, make width of road *outside* the centre line equal to $1{,}600 \div$ radius of curvature in feet; this will suffice for a wagon and team of eight mules in pairs.

In the Indian frontier campaigns several military roads have had to be constructed, and where zigzags were introduced, in most cases accidents occurred. If absolutely unavoidable, the angles or turning places must be level not at a grade, and the road should be widened; if possible, they should be located on a natural ledge on the hillside, and so as to avoid much cutting (see *Fig.* 50). On the inner return of a zigzag very substantial guard stones or cairns should be placed to prevent overturning of wheel traffic through clipping the corners.

No zigzag should ever have an angle, but always an inner curve, if possible not less than a circle of 3 feet radius, or on the outer a curve of 50 feet radius. There should also be a masonry wall, no matter how roughly built, around the curve to prevent strings of animals trying to cut off the corner, leading to blocks of traffic and endless delays. Camels especially are inclined to offend in this way.

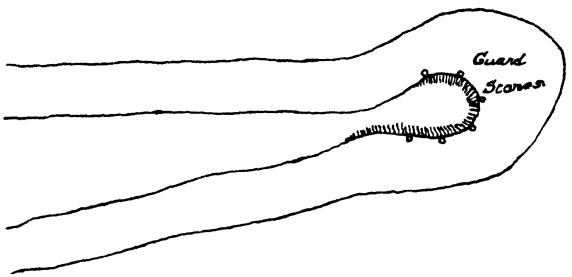


FIG. 50.—*Zigzag, Widened Turning Place.*

BRIDGE SITES.—These form obligatory points in a road; the following maxims should be remembered :—

(1). Cross a valley high where the stream is smaller; there is less liability to flood, and it is cheaper.
(2). A narrow gorge site is economical, as the river is not likely to shift, and probably rock foundations can be obtained.
(3). Single span, if possible; piers are liable to damage, but if the foundations are very sound, arches are easier to build; reduce the waterway as little as possible; place the arch springing above flood level.
(4). Cross well above flood level; this can generally be detected by examining tree trunk roots.
(5). Approaches to be straight, at least 20 yards at each end.
(6). Bridge itself to be straight rather than skewed.
(7). Descend banks upstream—(shortest route).

In crossing a ravine or deep chasm with a low-level bridge it is sometimes a gain to carry the road upstream, so as to reach the crossing in a shorter descent than if the approach were taken downstream.

(8). Bear in mind where materials for construction will come from.
(9). Leave old ford approaches undisturbed, if possible, to fall back upon during construction, and in case the bridge gets destroyed by flood or otherwise.
(10). Never reduce the bridge span by building out abutments, and so encroaching on the waterway.

Drifts and River Causeways.—"Nullahs," or water courses which are dry the greater part of the year, but which after heavy rain come down in flood with enormous force, have often to be crossed.

When lasting bridging materials are not available, small streams

are best crossed by means of "drifts" (see *Figs.* 51, 52, and 53). They should be constructed as far as possible during dry weather to allow settlement and consolidation to take place before freshets and floods come on.

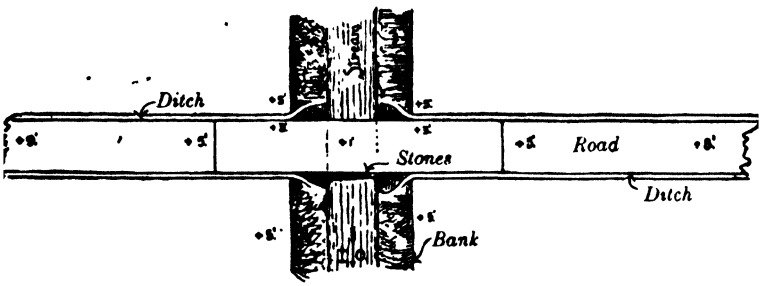


FIG. 51.—*Plan of Drift.*



FIG. 52.—*Section across Drift.*

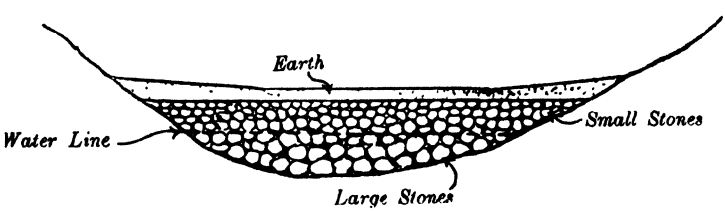


FIG. 53.—*Cross Section of Drift (Enlarged).*

Such streams have, as a rule, steep banks; the roadway should be ramped down 1 in 10 at right angles or obliquely to the banks upstream according to slope of descent; the foot of the ramps must be protected by "bunds," revetment walls, and "spurs" of timber, or large boulders, "sausage work" (see p. 142), placed close by upstream, to prevent erosion, and so cause a drop of from 1 to 2 feet each time a spate comes down and reduces the level of the nullah bed. In narrow nullahs not subject to heavy floods, 20 to 30 yards across, one method which answers well is to construct a dry stone drop wall on the downstream side with the largest boulders that can be obtained, finishing the top of the drop wall a foot above the

nullah bed, and sloping the face of the wall downstream to the nullah bed (see *Fig.* 54).



FIG. 54.—*Drift in Narrow Nullah not subject to Heavy Flood.*

In flood time the water becomes evenly distributed over the wall, and the *debris* which is brought down is collected up to the height of the wall, thereby raising the nullah bed; the height of the wall can then be increased, so as to increase the "make."

Another method—usually adopted in crossing sandy nullahs—is by dumping bags of concrete and rubble in lime finished off with slabs 9′ × 7′, 18 inches and 12 inches thick. Trenches on both sides of the causeway are first excavated to a depth of 10 or 15 feet, according to probabilities of scour; lime concrete is thrown in. Strong walls are then built on the upstream and downstream sides of the causeway, which is laid down, and consists of 2½ feet or more of rubble stone and concrete, finally finished with slabs or bags of concrete (see *Fig.* 55).

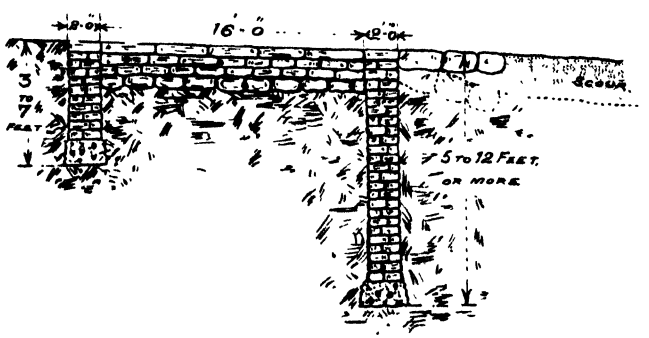


FIG. 55.—*Drop Walls and Causeway, to withstand Scour.*

This method is more expensive and usually involves the employment of a gang of men for removing the sand, which collects daily, due to wind or flood.

In building drifts, put on one or two gangs to complete the work without change. Avoid dividing up gangs.

With large rivers subject to flood it is better to assemble big boulders across the bed of the stream and level up with smaller

stones ; then lay a foundation of large stones and spread metal on top to form a roadway. This forms a sort of open dam, which will allow the water to flow through instead of over the causeway.

Causeways of large boulders act well where not much water flows down, but in floods they get carried away.

If heavy floods are to be expected, it is generally best merely to ramp down both banks and clear the nullah bed of boulders, so that wheeled traffic can pass. After each flood the nullah bed must be cleared afresh.

Protection of Fords.—A ford can be conserved to withstand heavy floods and scour by being protected with a timber crib weir filled with large boulders, the crest being formed with a stout log.

It is better to be content with a safe ford than attempt cheap bridging, providing a substantial bridge structure later when funds admit.

The approaches to a ford should be carried into the water ; they should be well pitched to provide good foothold, or metalled and drained for 200 yards or so on both banks, else they will soon become "poached," or deep in mud, from water dripping from animals after crossing. It is advisable to station men to scrape and clean the road, as animals invariably stale after crossing a stream, and soon render the ford site insanitary.

Snow must be reckoned with over 8,000 feet above M.S.L. in India as practically permanent in higher latitudes, and occurring for a shorter period and at greater heights as the equator is approached ; it is much worse than rain for damaging the road surface and substratum.

In mountain roads, through high passes which have to be cleared in the spring when the winter snows begin to melt, it often appears difficult to locate the track in the absence of telegraph poles, especially where the road doubles back or zigzags up a mountain side. It has been observed that, however deep the snow, light will be refracted at a slightly different angle from the snow overlaying the track, owing to it sinking as the roadside drains discharge. This difference can easily be detected, in a good light, by an observer at a short distance below the track, who can then direct a man along the alignment without difficulty.

In this connection it should be noted that the best approach to the head of a valley or obligatory point, from an *engineering* point of view, may happen to be through a ravine so sheltered from the sun that snow will remain unmelted for weeks longer than on another less favourable approach, and so block the road for a longer period.

In such a case the less favourable approach for construction purposes would have to be adopted.

Snow drifts are caused through the currents of air, carrying snow close to the ground surface, being checked, when the snow will immediately subside. Cuttings on fairly level ground, in this way, get quickly blocked.

The usual remedy is to erect *high, close* fencing across the direction of the prevailing winds at sufficient distance from the edge of the cutting that the snow will pile up on the windward side, and not extend into the cut. Open pale fencing and hedgerows along a road allow snow to blow through, though they check the wind; consequently fences should be entirely open or quite tight.

As a rule, deep cuttings through knolls and mounds which rise abruptly require no protection, because, after the wind blows the sides of the knoll bare, little snow will be blown into or over the cutting, most of it being carried round the base.

Stone walls, 13 feet high, 7 feet base, are used on the Italian Meridional Railway, and also in Hungary and U.S.A. In Russia post and rail panel fences, fixed to old sleepers, are very general. Panel fences may also be portable and leaned alternately one against another, crossed, and secured by bolts at the tops and tied by strips at the feet.

On Russian railways stunted pine and fir hedges are planted, up to three or more rows, and 150 to 175 feet from the track.

In shallow cuttings, in the absence of timber, it is frequently possible to grade the slopes to 1 in 10, and pile up the excavated earth as a snow fence beyond. The flattened slopes will afford an easy course for the wind, which, in this way, will blow a cutting clear.

Avalanche Tracks.—Avoid places where avalanches have occurred; they are sure to occur there again. Therefore, if these spots must be passed, build snow sheds or "tunnels." Good examples may be seen in the Caucasus roads, in the U.S.A., and in Canada (see *Figs.* 56 to 60).

The usual plan adopted in the Caucasus is to have two routes, one



Sheds at Avalanche Tracks.

covered or tunnelled, adjoining the mountain slope, the other open alongside; the latter is used, whenever the road can be assured clear, *i.e.*, after avalanches have fallen, or when clear of snow and safe.

The "tunnel" or shed is made thus:—High and low retaining walls, with a pent or trussed roof, according to space, etc., so that the contour slope of the mountain side is more or less kept to. If of any great length, it should be lighted artificially (see *Fig.* 56).

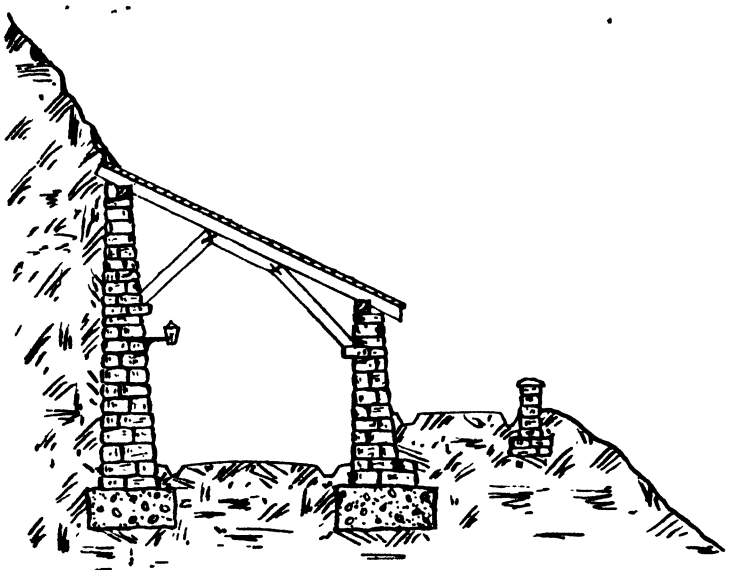


FIG. 56.—*Snow Shed, Caucasus.*

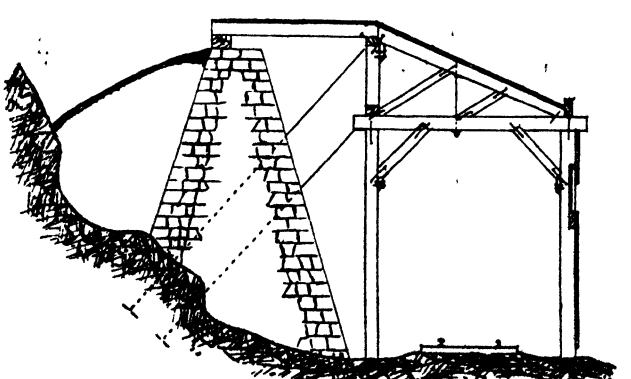


FIG. 57.—*Snow Shed, Central Pacific Railway.*

The roof may be merely of galvanized, plain, or corrugated iron on timber. Though in itself not sufficient to stand the direct *fall* of avalanche of mass of snow, earth, and stones, still the corrugated iron presents a good smooth slope for the mass to slide over; the momentum will invariably carry it over the outside track.

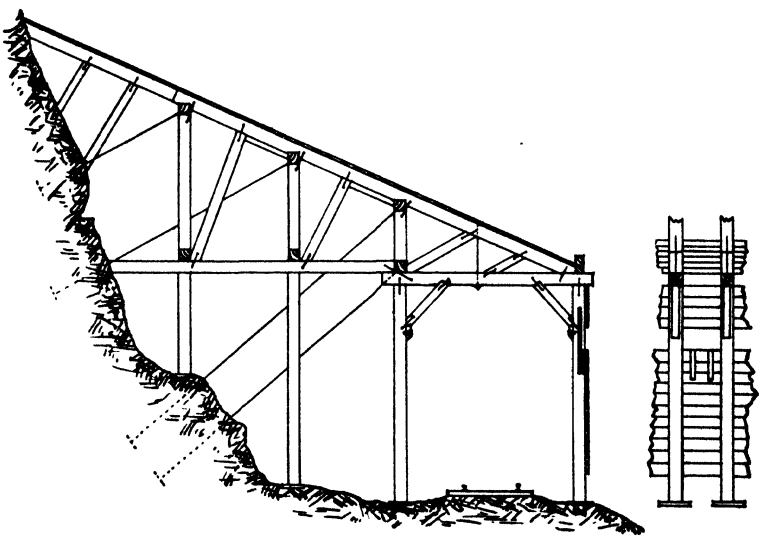


FIG. 58.—*Snow Shed, Central Pacific Railway.*

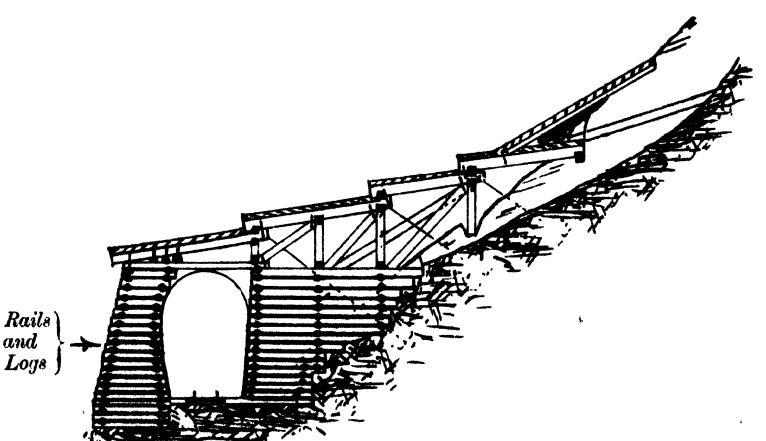


FIG. 59.—*Snow Shed, Denver and Rio Grande Railway.*

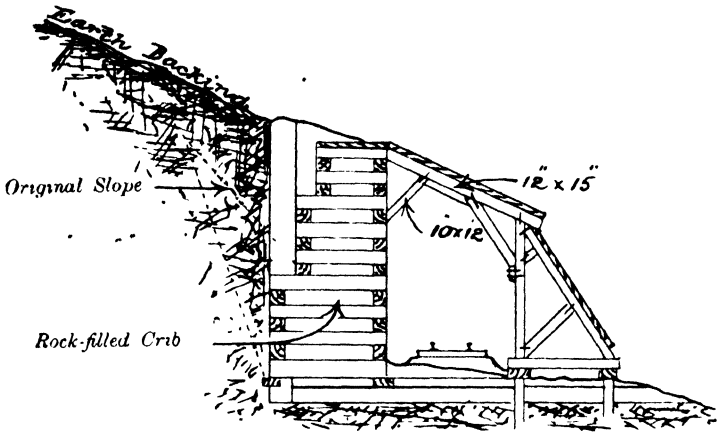


FIG. 60.—*Typical Snow Shed, Canadian Pacific Railway.*

The Swiss method of dealing with avalanches is to prevent their development and gathering by building cross walls in herringbone plan to overlap along their track, so that the *débris* falling on one is deflected, and becomes piled back behind the next.

LANDSLIPS.—These are most troublesome to deal with. As a rule they are due to ponded up water, land springs, faults in strata, frost, natural earth movements, fresh excavation.

Emergency Remedy.—(*a*). In rocky strata, build a retaining wall at the toe and divert water above—away to either side of slip.

(*b*). In loose strata, revet with wall, and terrace back the slope with fascine steps, pickets, turf, etc.; afterwards plant grass, shrubs, and willows (see *Fig.* 61).

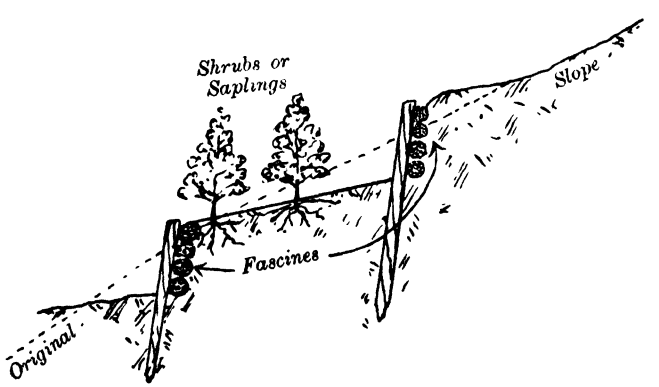


FIG. 61.—*Landslip in Loose Strata.*

Shale and clay slips are the worst; often they cannot be stopped. One expedient is to pile and pack in branches, or else clear away and wait until the dry season; then dig away, build a very stout retaining wall with plenty of dry packing (stone and boulders), and provide good drainage over the top; plant grass and shrubs abundantly.

Another plan is to burn the clay *in situ* with an admixture of fuel, as in a brick clamp; then dress down the resulting clinkers to a suitable slope.

If a slip of earth—overlying rock—starts, let it go, and encourage by adding water.

If a road is breached, re-bridge at the same site, but do not cut back into the hillside out of the alignment.

Irresistible landslips which foil all remedies must be left to work out and settle of themselves in course of years.

Where it is necessary to build up from the river-bed a retaining wall for a roadway, as for instance on a narrow terrace at the foot of a steep cliff which has slipped, and there are no means of laying dry the bottom, it is best to employ timber cribwork filled with rubble in preference to a masonry wall, which, unless very securely founded, is easily undermined by a mountain torrent.

Slipping "nullahs" (water courses) are best arrested by cross walls built at short intervals and projecting just above the level of the water-course bed, using the heaviest stones available. These cross walls are not meant to act as retaining walls, but to arrest and reduce the water velocity. No small stones should be used, as water must pass freely through the interstices.

Cross Section.—The same rules as given for roads in civilized countries apply more or less, but on hill roads there has been a great difference of opinion.* The main object is to get all water falling on the road surface to pass off by natural means as rapidly as possible.

Usually it is stated in text books that a hill road should have an uniform inward slope the whole way towards the inner edge.

The chief argument *in favour* of this is that all water drains into the gutter, and does not go over the embankment without proper means of discharge, and that the super-elevation eases traffic and reduces outward pressure and danger; the construction of parapet walls will to a certain extent obviate the latter.

The reasons *against* are that, as heavy traffic tends to clip corners, the drain gets soon and easily damaged; attendant on this, water collects, and as the traffic will continue to hug the inner face,

* The whole question of cross section has been very fully discussed by Colonel Wilkins, R.E., in his *Treatise on Mountain Roads and Bridges*. Thacker (Bombay), 1879.

the outer portion of the road will not be used. The road therefore gets scoured out into a sort of water course; to some extent this may be prevented by the judicious use of guard stones.

By using a barrelled cross section and a parapet wall, say 2 feet high, 1½ feet thick, the outer drainage can be turned off at safe places, and if one part gets damaged, vehicles can avoid it easier.

Some engineers prefer an outward slope, to cast off all water, but experience is generally in favour of the barrelled section. For cart roads and paths in the hills, and when the width is less than 16 feet, an *inward* slope should be given.

Fig. 62 gives the *half or modified barrelled* section.

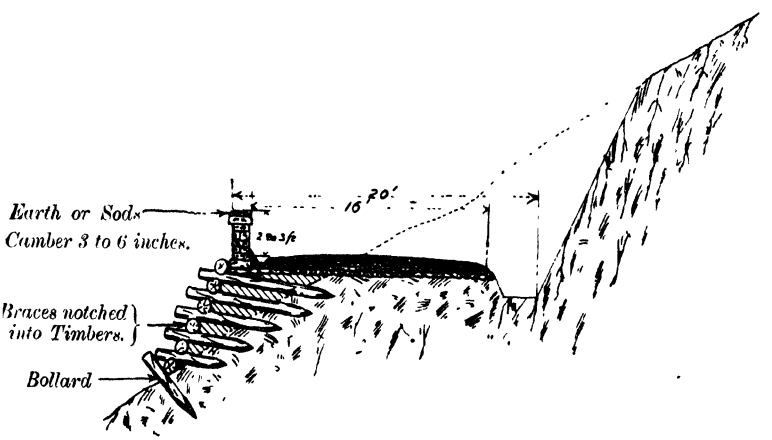


FIG. 62.—*Modified Barrelled Cross Section.*

The slopes should be adjusted so that drainage will flow to the side channels and not down the road, *i.e.*, the slope where possible should be steeper than the gradient.

Where the road runs along steep hillsides, it has often to be cut half in cutting and bank, more or less. The embankment is then supported with dry stone walling; the natural slope should be cut into steps before the bank is formed, or a log revetment may be employed if timber is plentiful (*Figs.* 42, 48, and 63).

Sometimes the cutting requires similar support, and the batter should then be 3 in 1, the base being horizontal. In both the back face is vertical, or nearly so.

For tables of contents in sidelong ground, retaining walls, natural earth slopes, etc., see *Molesworth's Pocket-Book*, edition 1905, pp. 76—80 and 90.

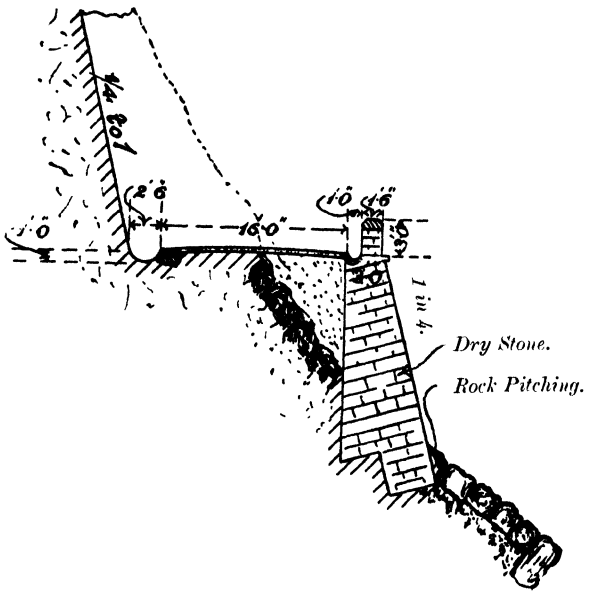


FIG. 63.—*Mountain Road Section in Steep Rock.*

DRAINAGE.—Most important; there are :—

(*a*). Side drains.
(*b*). Cross drains under and over the road.
(*c*). Catchwaters.

(*a*). *Side drains* take water flowing down face of rocks, etc., between catchwaters and the road; they are very liable to scour; they should be paved and properly connected, with cross setts every 10 to 15 feet to check velocity; also water cushions (see *Figs.* 64 and 65) every few tens of yards, according to gradient and amount of water. In the hills these depressions fill up too rapidly to do much good. When crossing marshy ground the side drains should be deepened to 2 or 3 feet, and made 2 feet wide.



FIG. 64.

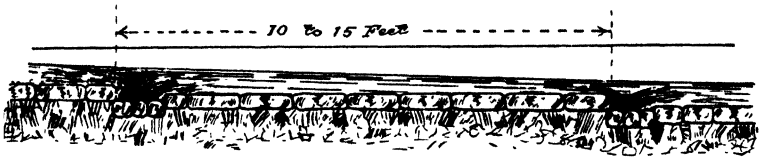


FIG. 67.—*Section at A.B. and Water Cushions.*

Drains should not be taken round curves, but continued along the tangent and taken *under* the roadway, so as to discharge with a straight course over the lower slope.

A long drain on a steady grade will be more efficient if made gradually larger from the upper to the lower end.

(*b*). *Cross drains* under and over the road. Water may be carried *under* a hill road by :—

(i.). Permanent bridges and culverts.
(ii.). Dry stone culverts.
(iii.). Corrugated iron or reinforced concrete pipe culverts (see p. 130).
(iv.). Percolating causeways of large boulders, assembled with ample interval.

Water may be carried *over* a road by :—

(i.). Paved crossings of dry stone hammer dressed.
(ii.). Saucer drains of dry stone paving.

Dry stone and corrugated iron pipe culverts get undermined and washed out where liable to a heavy rush of water; the latter, however, are easily replaced.

Saucer drains jar traffic, and should be replaced whenever possible by small culverts, to pass the water under the road. If used, they can be filled up during the dry weather with gravel and shingle, which will get quickly washed out with the first heavy rainfall, when the drain will serve its purpose.

On some second class roads drainage is often arranged so as to be arrested at intervals, and run across the roads by a system of cross ridging by diagonal lines of stone setts or planks. This is not a sound arrangement for wheeled traffic; if made so they should be covered over, else in case of landslip they will get choked; on the other hand, in hill *paths* for mule traffic the arrangement is most useful.

Cross drains should be carried at right angles under the road; oblique drains are longer, and introduce acute and obtuse angle terminations to piers and abutments or coverings, but, on the other hand, provide an easy change in direction of flow of the water. A catchpool should be provided at the head of every cross drain or

culvert for arresting boulders and *débris* washed down from the ravines above. The bottom of a catchpool should be a foot or more below the floor or sill of the cross drain. Unless in rock, the sides must be lined (see *Figs.* 66 and 67).

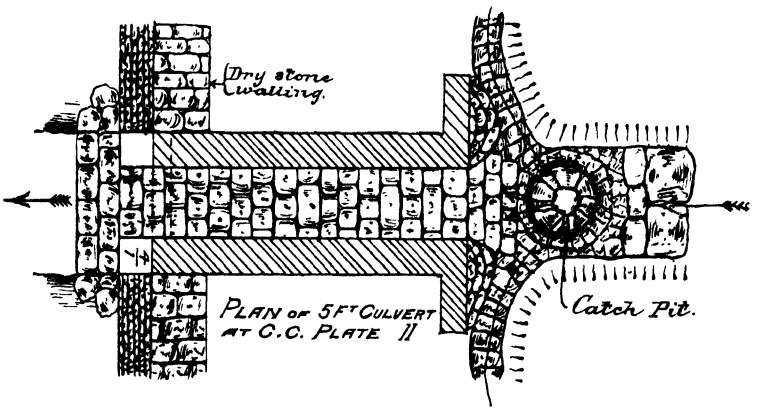


FIG. 66.—*Culvert and Catchpit.*

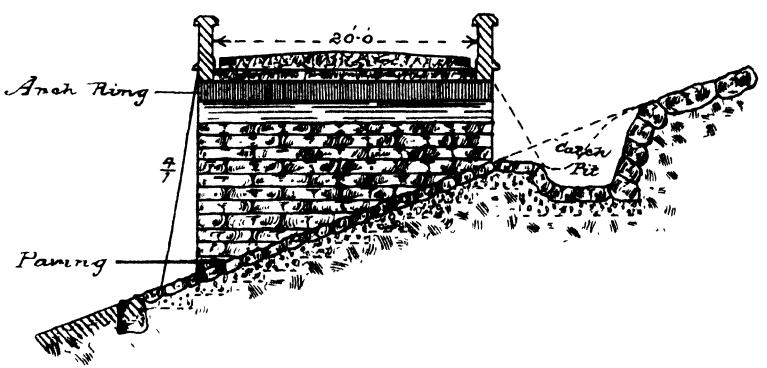


FIG. 67.—*Section through Culvert and Catchpit.*

With paved cross drains the blocks of stone used should be closely fitted together in the actual bed of the crossing, while those on the apron below should be very massive, with as gentle a slope as possible, so as to break the cataract of flowing water.

On both sides of the crossing the longitudinal slope of the road should either be level or sloping towards the crossing. There should not be a *falling* grade in either direction, from the crossing to the road surface.

(*c*). *Catchwaters* are provided 15 feet to 20 feet up a hillside, to carry water from the higher slopes away from road site, and prevent any falling upon the road. They are arranged as inverted V's, to follow the contours and discharge into catchpits and leading under the road through a culvert (*Plate* II.).

On some mountain roads, where the rainfall is excessive, they may be as wide as 25 feet, and 5 feet deep (Lahore-Peshawar Road); elsewhere, 10′ × 3′ deep (Kangra Road). In general, never less than 6′ × 2½′ deep. The sides and bottom require pitching.

A slight fall (1 in 125) in the length of the road assists drainage more than crowning of the cross section.

Any waterfall shooting over a road site or cliff must be treated in the same way by being cut back and conducted under the road by a culvert along the level floor, or over steps cut in the rock. Collect large boulders under the fall to break the momentum of the falling water.

Every spring that is tapped should be carefully preserved from contamination by troughs or barrels placed in a hollow beside the road.

It should be noted that the mere excavation of a wide road along a hillside at once alters the whole system of natural drainage; it is useless, therefore, to commence drainage works until after the experience of one rainy season. Also that small drains in tropical climates subject to sudden and heavy rainfall are quite useless; 2½′ × 2′ should be the minimum size in such cases.

It cannot be too strongly impressed upon subordinates in charge of road gangs how essential it is to maintain road drainage in first-class order.

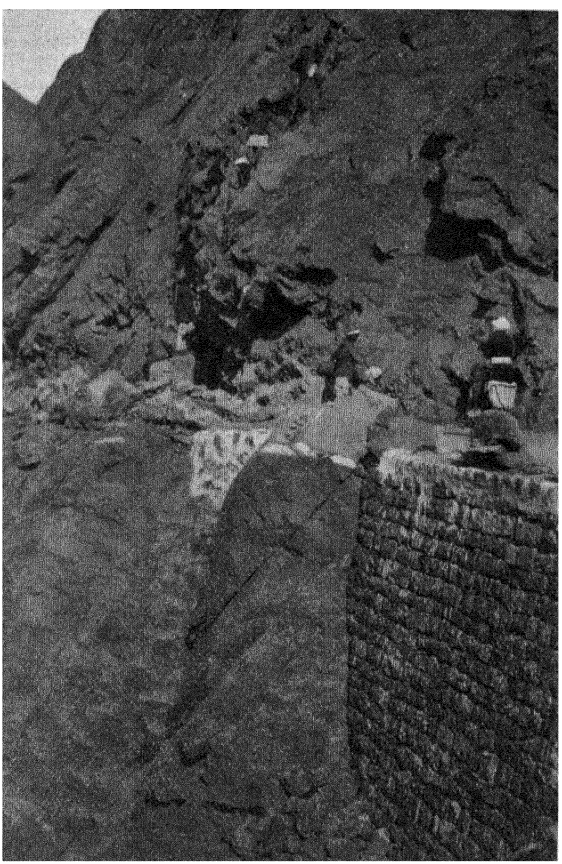
An unusual type of road construction is followed in Sikkim and Assam, which is found to withstand torrential rains and remain passable This paving is practically a continuous Irish bridge; large stones or logs (the latter are best for hasty work) are placed on the outer and inner limits of the track, and the centre filled with stones *on edge*, very firmly wedged and hammered in; any sharp projecting points are then broken and roughly smoothed with a heavy hammer, and the whole covered with sand or gravel. This kind of track remains passable in any kind of weather, and is very lasting for pack-animal traffic. Some maintenance is necessary, to the extent of keeping earth spread over the stones, as otherwise mules and ponies are apt to get lame. When tree trunks are used, as on corduroy roads, on a grade they must be very firmly battened down by stout ribands at each side, to prevent the logs creeping and leaving awkward gaps.

Retaining and Breast Walls.—These are usually built dry in coursed rubble or random rubble, coursed at convenient heights not exceeding the breadth of the road; careful bonding of the founda-

tion is the key of success; they must always be founded on the original, not made ground; special attention must be paid to the bonding of the hearting. They can be calculated or designed graphically (see *Molesworth's Pocket-Book*, 1904, pp. 86—90).

Rough rule—2 feet or 2 ft. 3 ins. wide at top (18 inches if less than 4 feet high).

Front slope—4 to 1 or 4½ to 1 ordinary; 3 to 1 if surcharged (see *Hurst*, p. 127). Back vertical—base at right angles to front face or sloping; in soft soils both faces may batter. Inner—8 to 1.



Dry Stone Walling.—Hazaras Widening Road and Removing Dangerous Rocks.

High walls require a good masonry in mortar foundation, 2 feet thick; walls over 12 feet should have courses of masonry in mortar, say, every 6 feet of height.

The rules laid down by General Fanshawe, R.E., for thickness at base in decimals of the height for various batters were as follows:—

·24 H, batter 5 to 1.	·28 H, batter 12 to 1.
·25 H, „ 6 to 1.	·30 H, „ 24 to 1.
·26 H, „ 8 to 1.	·32 H, vertical wall.
·27 H, „ 10 to 1.	

Sandstone as a foundation, however hard and durable it may appear, is unsuitable; under the influence of tropical rains and sun, in damp situations, it will soon disintegrate into sand.

Boulders and stone chips, *not earth*, should be filled in as backing.

Where "rifts" have to be filled in with dry stone walling, the bottom and sides should be benched so as to bond the masonry into the rock; ends and foundations of the wall should be built with mortar.

Lay courses *longitudinally* horizontal, in regular courses throughout the wall, from the outer to the inner face, sloping inwards; step foundations; use long "headers" to give through-bond. When skilled walling masons are not available, bond may also be obtained by introducing wooden frames of notched and spiked timbers at vertical distances apart, not exceeding the breadth of the wall; but they will rot, and so become a source of weakness in course of time. Face stones may be anchored back by iron bars, hoop iron, or telegraph wire, expanded metal, or netting tarred and sanded. Drains or a concrete apron should be laid along the foot to protect the foundations; weep holes should *always* be provided (refer *Trautwine Pocket-Book*, p. 683, *et seq.*). In any case, the toe and top must be protected with earth if a concrete apron coping is not built.

PARAPETS.—Parapet walls are essential for safety, especially in deep gorges. The stones should be large, else carters will remove them to chock up wheels at a halt, or use to form camp kettle fireplaces.

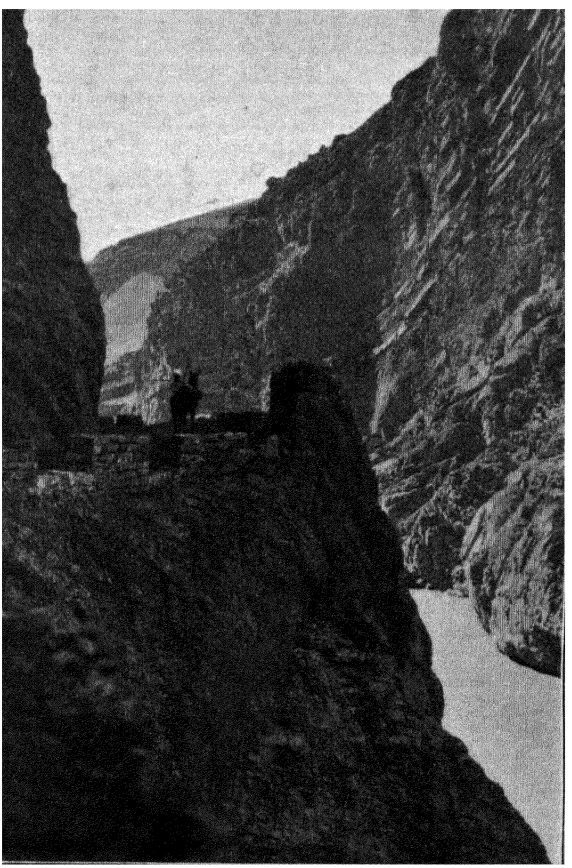
If large stones are not available, use a cement coping, or one of sods or earth, as a temporary expedient. Parapet walls with the copings topped with earth are less tempting as seats; the stones also will be less liable to become detached by pedestrians leaning over.

Allow ample openings, say one every 20 feet, for the passage of drainage and removal of *débris;* openings should not be less than 3 feet or 4 feet without some cross-bar protection.

Giant boulders form good substitutes for masonry parapet and walling, but are usually too bulky for the width of roadway if this is less than 16 feet.

Open parapet formed of railway bars built in between masonry pillars affords a satisfactory protection (see p. 77).

On bad or made ground, fencing, where necessary, should be light, but substantially fixed so as not to be removed, as on the Indian Frontier, for the sake of the metal; iron, not wood, should



Road in Deep Gorge—Hard Shale. Open Parapet—Masonry Pillars and Iron Rails.

be used, as less liable to decay, removal for firewood, etc. Where snowdrifts occur fencing should be either quite close or entirely open (see p. 61).

SUNDRIES.—*Camping grounds* should be arranged for every five miles, or at longer intervals, on mountain roads; trees should be planted and spring water conserved.

Water Troughs.—Butts or tanks of galvanized iron, masonry or concrete, as convenient. Arrange in series both for men and animals.

Guard Stones.—3 feet high, and sloping to be substantially sunk 18 inches into firm ground on the inside of all curves. Rough rule—half out, half in ground; lower half rough dressed.

Milestones and Signposts.—Marked on both faces to read up and down; use for bench marks; they should be set up on the same side of the road throughout; figures 4 or 5 inches in height, painted black on a white ground, so as to be very distinct (see *Figs.* 68 to 70).

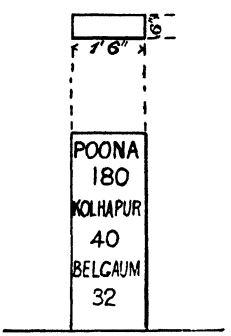


FIG. 68.

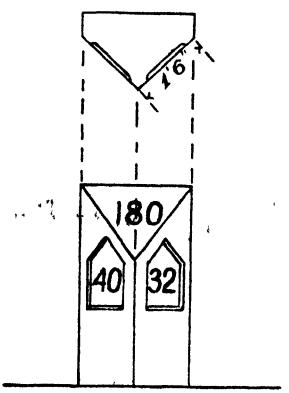


FIG. 69.

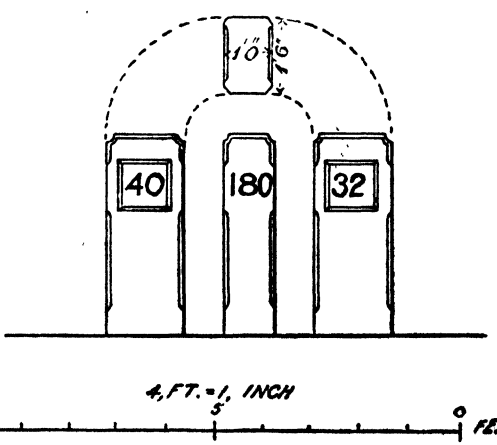


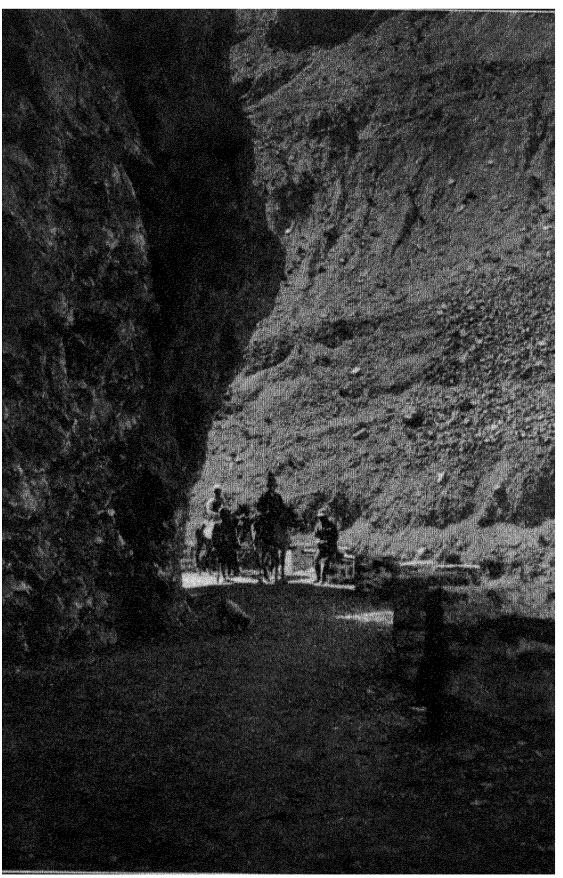
FIG. 70.

Stacks of Metal.—Stack to proper trapezoidal shape in the "cess" cut out at roadside, 1,000 cubic feet per mile. Arrange depôts and emergency stacks. Whitewash all metal stacks after measurement and inspection.

Culverts and bridges should be numbered and recorded in a register with mileage.

Precipice Work.—A road may be constructed along a precipice either by :—

(1). Cutting down from the top.
(2). Blasting out a half-tunnel.
(3). Forming a cliff gallery.



Precipice Work.—Heavy Rock Cutting in Deep Gorge.

(1). *Cutting down* is resorted to in loose rocks, and may entail considerable masonry face work and breast walling, depending upon the character and slope of the rock face (see *Fig.* 71).

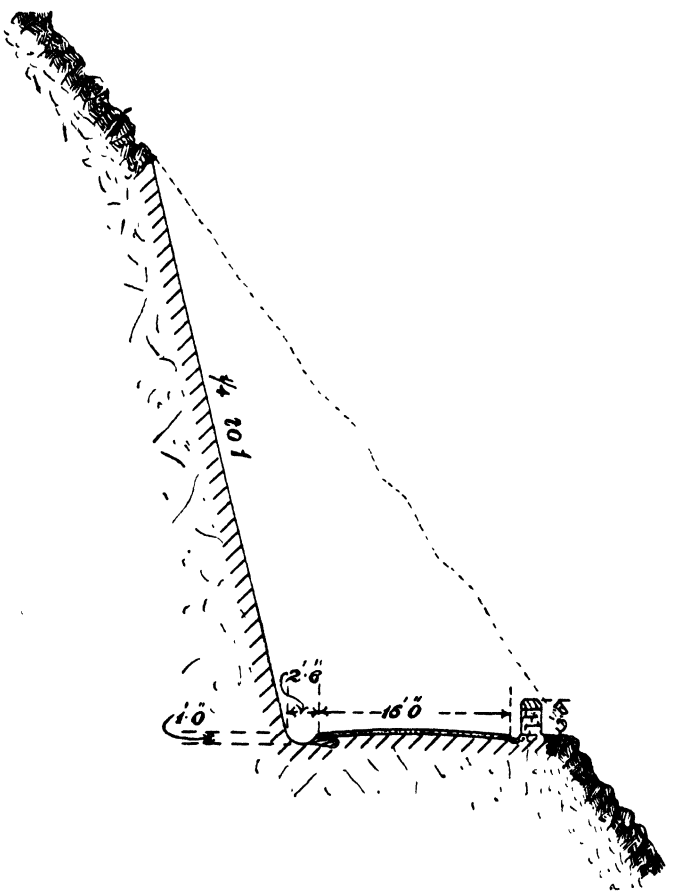
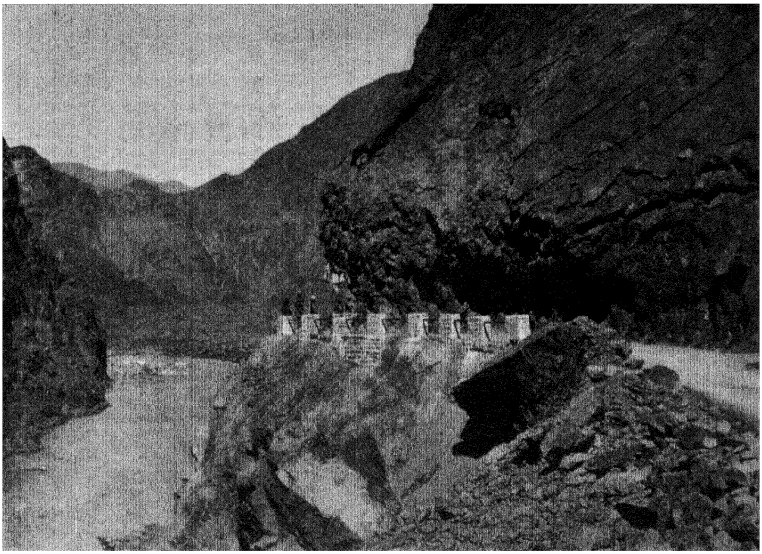


FIG. 71.—*Precipice Work.—Cutting Down from the Top: Loose Strata.*

(2). *Half-tunnels* can only be made with safety when the rock is hard, sound, and free from dangerous fissures; otherwise it is best to cut down or make a cliff gallery if the side slope is too precipitous.



Military Road, India.—Half-Tunnel Work in Hard Shale. Open Parapet—Masonry Pillars and Iron Rails.

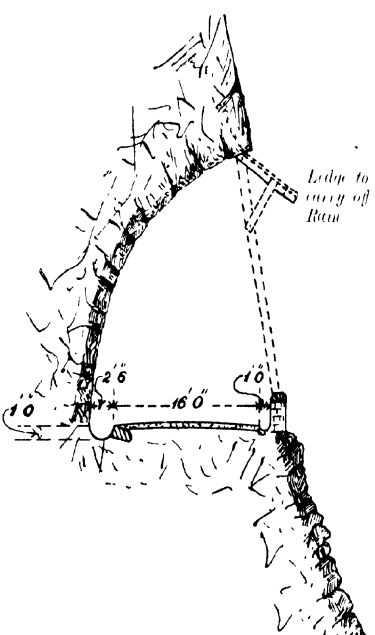


FIG. 72.—*Half Tunnel in Rock*

The rock is blasted out from a lodgment formed about 20 feet above the intended road level (see *Figs.* 72 to 74), and dressed off; if the rock is too soft and rotten to admit of this, it is better to blow out the whole by a large mine, and resort to cutting back (see *Fig.* 71). All this requires care and the use of *long* safety fuze; road levels will, of course, get lost unless independently checked by outside measurements.

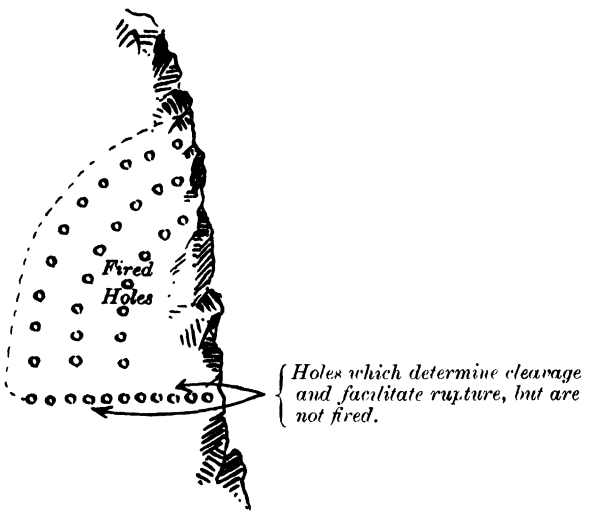


FIG. 73.—*End Attack of Face for Half Tunnel.*

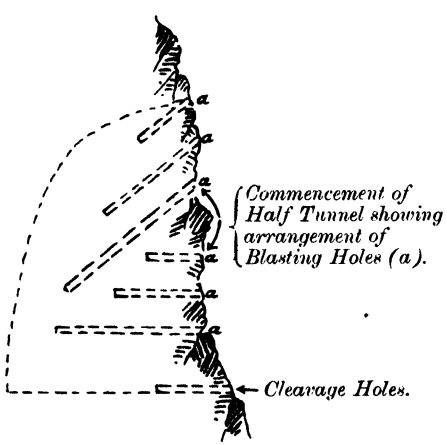


FIG. 74.—*Face Attack for Half Tunnel.*

(3). *Cliff Galleries.*—These are usually the outcome of the local people being unable to blast (as in Baltistan, Indus Valley, etc., India). They are troublesome and dangerous to construct, but often the cheapest and simplest arrangement where the strata are inclined inwards from the face, thereby affording easy attachment for the jumpers and holdfasts (see *Figs.* 75 to 77).

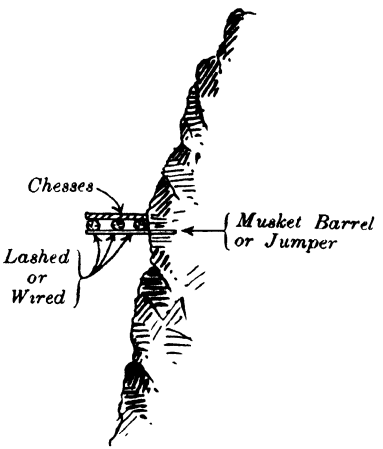


FIG. 75.—*Cliff Gallery.—Temporary Track.*

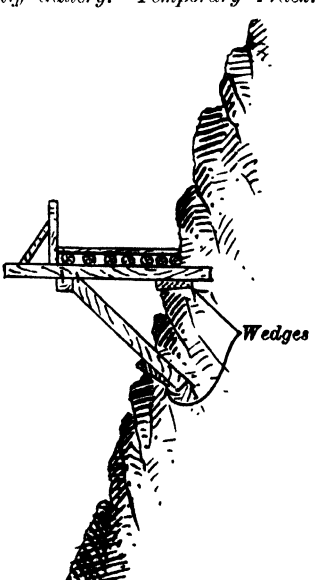
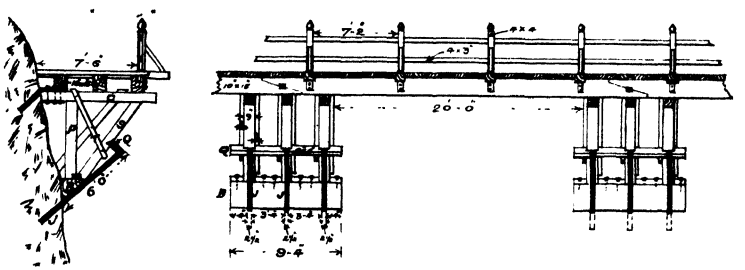


FIG. 76.—*Cliff Gallery.*

The road is carried by chesses resting on projecting timbers or brackets secured to the face of the precipice. To obtain a foothold of some kind it is necessary to lower down one or two men from the top to the proper level, armed with a crowbar and jumping tool, etc., to make a hole in which to place the crowbar. It is a tedious process, but effective when complete ; gun-barrels will do instead of crowbars as temporary supports.



Transverse Section of Cradle and Roadway above it.

Elevation of Two Cradle Piers and Intermediate Bay.

FIG. 77.—*Cliff Gallery.*

REMARKS.

A is a bent jumper 3' long, of which 18" are let into the Cliff and 18" secured to the capping piece.
B Sill Block.
C Cradle Cap 9" × 9".
J Stanchions of Bar Iron 2½"
P Cradle Posts 9" × 9".
Q Stanchion Cap 6" × 4".
S Cradle Struts 9" × 9".
T Braces.—notched into struts and capping piece.
The spans of the girders are not of uniform length ; they vary from 15 to 25 feet. As a rule 18 and 20 feet are found the most convenient spans.

If the top of the precipice is inaccessible, the only way is to scale from below, or commence at the end of the road as far as it has been brought, jumping holes and driving in crowbars a few feet in advance of a log projected forward along the surface.

Another plan which may be applicable is to pass two ropes along the face of the cliff from two accessible points on the road trace, one as a hand-rope, the other for foothold, the latter being obtained with a double stirrup or small platform suspended from it, upon which a man could stand and work. The cables would have to be strained until the man was at the right height, and in order to keep it close to the face of the rock.

The chesses and cross-bearers of the cradle should tilt *inwards*, lest, when the cradles draw away from the face of the cliff and lean forward when the roadway becomes loaded with traffic, the surface should slope outwards and be dangerous (see *Figs.* 78 and 79).

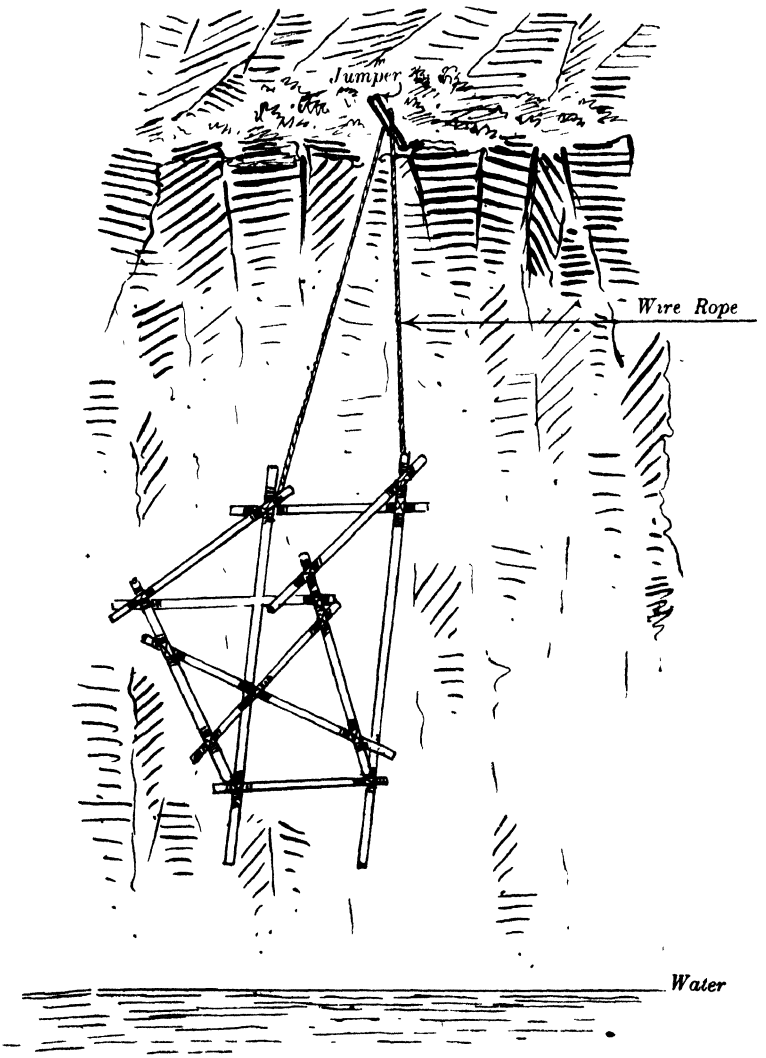


FIG. 78.—*Cradle.*

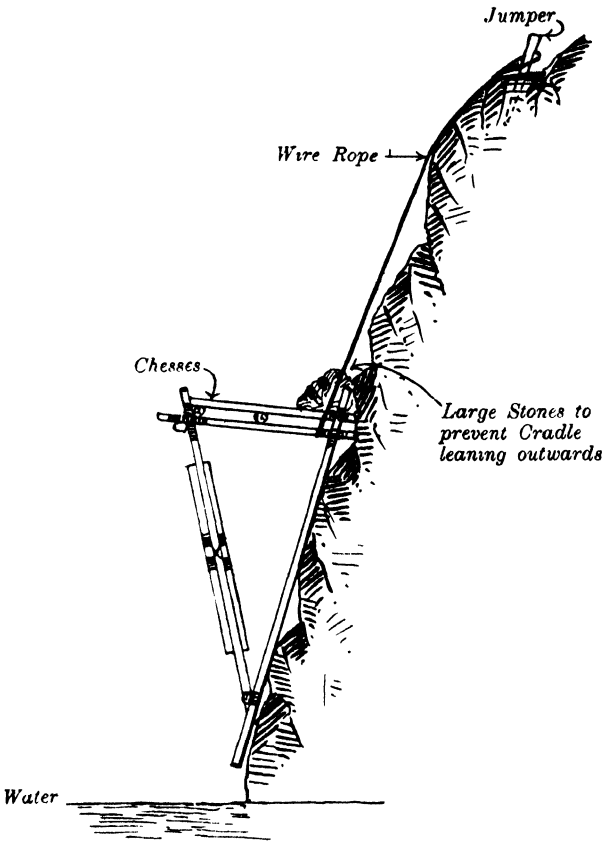


FIG. 79.—*Section of Precipice and Cradle in Position.*

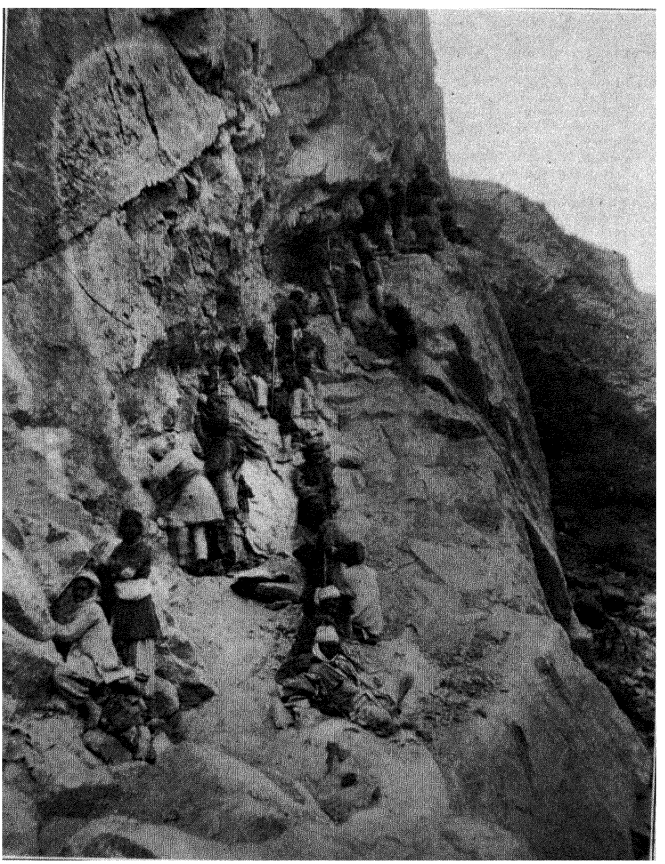
BLASTING.—Employ task work, if possible, under skilled (European or intelligent native) supervision; a few of the best of each gang may have to be taught in the first place; the task for each pair may be taken as four holes (1½ inches) of average depth, which can be completed by hand in seven to eight hours.

The chief difficulty with native quarrymen is to prevent them wasting time and explosive in sinking shallow blast holes.

The ordinary daily task of boring, per man, is 60 inches in sandstone or conglomerate, 45 inches in limestone, and 30 to 32 inches in granite. With steel boring bars and hammers, 3 skilled men (2 strikers, 1 borer), with a 2-inch bar, should bore 8 feet of granite in 10 hours.

Charging, tamping of holes, preparation of fuze, and firing should be done by an European; natives do not understand the violent action of explosives. Black pebble powder is best for "shaking" rock. A barrel contains 100 lbs.; 1 lb. occupies 30 cubic inches.

Dynamite is better than guncotton, as it can be rammed with a wooden or copper-tipped rammer into any size hole, and fired with a commercial detonating cap. Ammonal is a very safe substitute.*



Blasting a Road on a Cliff Face.

Before firing a charge, it is necessary to see that the earth has been removed from around boulders and rock, otherwise, only that portion above ground will be broken.

* Ammonal Explosives Co., 29, Great St. Helen's Street, E.C.

"Kankar" rock (limestone conglomerate, resembling petrified sponge) is very tough, and hard to drill or jump.

In blasting fissured and honeycombed rock, the best result is obtained by using fine-grained powder, filled into very thick iron plate cartridge cases, with a small hole in the top for a priming needle.

In attacking a cliff with large mines, a line of scaffolding must first be erected along the whole face, and galleries $3' \times 2\frac{1}{2}'$ driven into the rock, chambers being formed at the end of return galleries to the right and left. Charges should be placed at a horizontal distance from the cliff face of 2 feet more than the proposed width of the road, to ensure masses of rock being blown out on *both* sides, in each case, to a distance equal to the least line of resistance (L), *i.e.*, with a 20-foot road and two chambers a length of cliff $(20 + 2) + 22 \times 2 = 88$ feet by 22 feet wide.

For powder, charges should be :—

In granite rock..... $\frac{L^3}{8}$,

„ limestone or hard sandstone .... $\frac{L^3}{10}$,

„ conglomerate, shale, and slate ..... $\frac{L^3}{12}$,

where L is in feet and the charge lbs.

Tamping of these galleries can best be effected in such impracticable localities by using sandbags made of native matting, filled with damp clay. Behind the charge $4'' \times 4''$ baulks are dropped, with chases cut in the sides of the gallery to hold back the charge ; then 10 or 11 feet of sandbags, closed with a 2-foot wall of sun-dried brick and 2-foot cushion of sand, the whole tamping being finally closed with another wall of 4-inch baulks (see *Fig.* 80). Time required to tamp, 12 feet per hour.

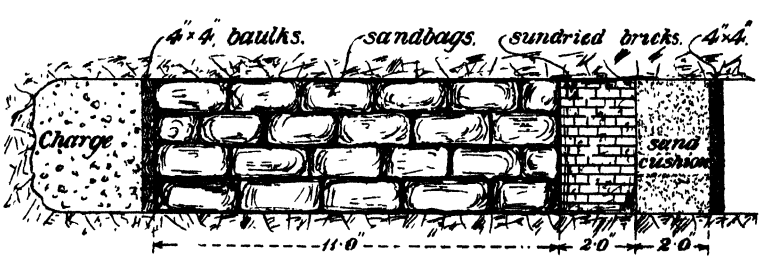


FIG. 80.—*Tamping a Gallery.*

It is usually much more economical and effective to fire several mines simultaneously than singly. Under these conditions it has been found that each lb. of powder may be reckoned on to dislodge

200 cubic feet of conglomerate rock, 115 cubic feet limestone, 75 to 85 cubic feet granite (Kangra Valley Road, Himalayas, 1872). Cost of excavation worked out to 7s. per 1,000 cubic feet. Ordinary blasting in single charges would be four times greater.*

For further information on blasting *vide Instruction in Military Engineering*, Part IV., and *Blasting*, by Oscar Guttman, published by Griffin, Strand.

The clearing of large rock masses detached by a blast may be expeditiously effected by exploding howitzer shells under or behind them, and fired with a fuze.

Amongst snow mountains, where fuel is abundant and blasting materials are not available, rock may be cracked and shivered sufficiently to be manipulated with crowbars by being alternately intensely heated, and then quickly deluged with snow water.

The use of nitro-glycerine at high altitudes, owing to its liability to freeze, is risky; otherwise, it is very handy to use in hardly accessible places. The charge may be tamped by filling the blast holes with water in sealed rubber tubing if there is any likelihood of it escaping or being absorbed into the rock.

Roads during Military Operations.—The military importance of roads is but imperfectly appreciated in the British Isles. Continental nations have had the bitter experience of war; in this country our experience is confined to a few weeks' manœuvres in recent years.

Few persons have any idea what military traffic, continuous for months, means. The high roads will stand it, no doubt, but many of the contributory roads would fail utterly after a few weeks; it is just these roads which would need to be used and kept clear, else the main routes would very soon get blocked.

Moreover, it is practically certain that self-propelled transport will figure more largely than hitherto in any area of military operations; hence the necessity of constructing roads which will withstand the traffic.

It must also be remembered that bridges and culverts will, in many cases, be destroyed, and, until replaced, deviations will be necessary. To construct such with material which will consolidate rapidly and withstand continuous traffic is difficult. It is probable that the Gladwell process of metalling (*vide* p. 105) will likely prove effective in such cases, but the essential ingredient, tar, may not be immediately procurable.

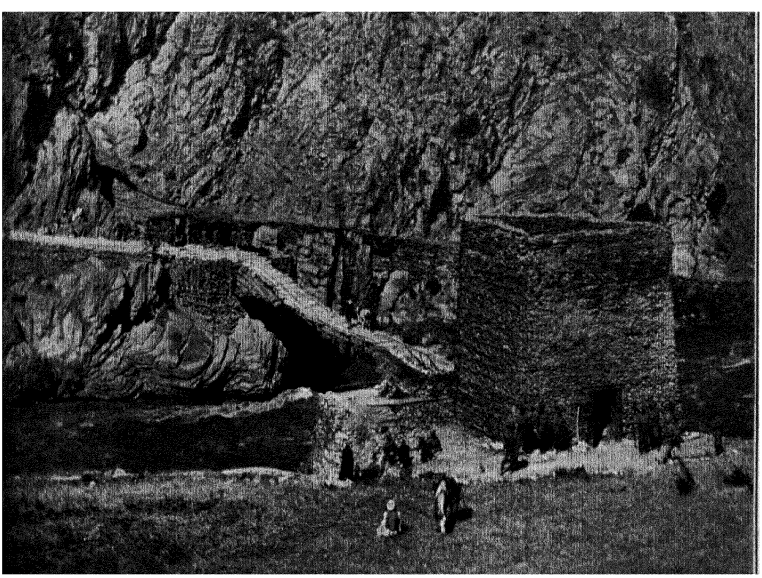
During military operations in hilly country temporary roads are often required, and have to be made rapidly, prospecting, tracing,

* *Minutes of Proceedings of the Institute of Civil Engineers*, Vol. XXXVIII., page 77, "Mountain Roads in Tropical Countries," by Major James Browne R.E. (the late Major-General Sir James Browne, K.C.S.I.).

and construction proceeding simultaneously. They should be made as *short and straight* as possible, even if it is necessary to adopt very steep grades. Long teams of draught animals are useless round curves and zigzags. Even if the grade is very steep, a block and tackle can be attached to assist.

The necessity of improving the alignment and grade along the main route should always be kept in view.

If there is any likelihood of a narrow hill road—say 6 feet—being eventually widened to a cart road, then work to a cart road gradient (see p. 55). A 6-foot mule track at 1 in 20, when widened to 12 feet or 16 feet, will probably work out to a grade of 1 in 16, which would be very steep.



Roadwork, Chitral.—Temporary Bridge and Bridge-head.

The longer the road is to be used, the greater the improvement desirable.

Steep temporary roads are very trying to transport animals, and unless improved as time admits, will increase the mortality considerably, especially if the military expedition continues longer than anticipated, which is usually the case.

A difficult place should never be passed without deciding how to get guns across. Men of the advance guard should be ordered to remove all boulders, trees, etc., which can be shifted without tools, from the track. Difficult ground often *appears* worse than it is found to be when a little engineering skill is applied. It often proves true that the road which is the hardest to cut is the best to last.

It pays best in the long run to attack difficult places at once, without seeking for easier diversions and detours, where lesser or equal troubles are often in store and occur unexpectedly (see p. 116).

One great evil may be more easily overcome than a number of lesser evils. Improvements can be introduced subsequently.

Organization of Labour.—In military operations on the Indian frontier, Coolie Corps are sometimes raised for roadmaking -- 1,000 strong, commanded by R.E. officers, of whom there should be not less than three, with three or four *picked* European or native subordinates with linguistic attainments and ability. Hazaras, Pathans, and Garwhalis are enlisted round Quetta, Peshawar, and Mussoorie respectively. They have to be organized and despatched in batches, *accompanied by an officer*, to avoid confusion, to the base. Whilst the corps are being raised and despatched to destination, the routes should be explored well in advance. Their organization requires considerable forethought as to equipment, food, and transport. Waterproof sheets and light tents must be carried by the coolies themselves. Huts can be erected at depôts formed later, as required. A reserve of tents and sheets should be available at an advanced base.

The staff required for work on a difficult transfrontier road (India) should comprise the following, their numbers depending upon the extent of the work:—

1 field engineer in charge, with office establishment, head storekeeper and assistant, 1 or 2 hospital assistants, with subordinate staff, commissariat and transport officer and clerks, and perhaps a personal assistant.

2 assistant field engineers, controlling and supervising 500 coolies apiece, and three or four sections of road each.

2 European or native overseers of experience to each assistant field engineer, with 5 sub-overseers, one for every 100 men, with 4 head masons, one to each section of 25 men.

This would give a total of 1,080, exclusive of military escort (see *Plate* III.).

Printed Standing Orders should be issued, and only amended where absolutely necessary, and as seldom as possible.

The senior officer in charge may have to arrange for the supply of food and issue of rations, not unfrequently at short notice, with the aid of an inexperienced staff; possibly, in addition, to organize his own transport (coolie or pack animal) and food for same. Definite understanding, *in writing*, with the G.O.C. upon this point should be arrived at, as the supply and transport corps may otherwise be unable to meet the demands of non-combatants.

The field engineer should be responsible for all organization and arrangements — correspondence, accounts, medical, commissariat, transport, stores, tools, and plant To his personal assistant he may delegate supervision of a portion as convenient. The field engineer should control and supervise the work as a *whole*, delegating such sections to the assistant field engineers, in proper proportions, according to the nature of the work and their capacity.

The assistant field engineers should exercise supervision over "divisions" of grouped "sections," and be made responsible for the arrangements, *in detail*, for rations, transport, tools, explosives, postal service, and works office in their own groups.

In the Tibet expedition 2,400 lbs. of food were consumed by 1,000 coolies *per day*; as many as 3,400 were catered for, which meant about 3½ tons, *i.e.*, nearly 100 loads for food alone per day, and, in addition, a like weight of tools. Each coolie carried an 80-lb. load per day over a five-mile stage; each pack animal two loads the same distance, over rugged and steep hills.—*R.E. Journal*, 1905, p. 293, "Construction of Nathu-la Road," Capt. R. St. J. Gillespie, R.E.

Overseers (European or native), sub-overseers, and head masons must always be on the site of works to give levels and bench marks to work to, assisting the contractor's gangs and headmen in every way.

Assistant storekeepers will be required at tool depôts, one to each assistant field engineer and magazine.

Tools and Plant.—The supply of tools will present difficulties unless careful arrangements are made in advance; the delivery at a railhead will, as a rule, be up to date, but the transport beyond must early be organized, and, if possible, experienced storekeepers engaged. An ample supply of portable forges and smiths' tools should be taken to sharpen the hundreds of jumpers in daily use.

Before indenting for or purchasing tools, it is desirable to ascertain, by personal observation if possible, what rock or soil is likely to be met with, and what proportion of blasting tools and explosive will be necessary. Some gravels are more expeditiously loosened and removed by explosives than with picks.

A list is given for 100 coolies working in ordinary country, with a few trees and a certain amount of rock.

Tools for 100 Coolies.

Axes, felling	12	
,, hand or "kukeries" (cutlasses) ...	30	
,, pick	60	
Bars, jumping (1½ inches)	15	
,, crow	6	
Bellows, braziers, small	2	
,, smiths' or forges (portable)	2	
Baskets for earthwork (or barrows)	100	
Carpenters' tools	2	Sets.
Hammers, masons'	6	
Knives, clasp	6	
,, line (100 fr.)	5	
Native hoes ("phourahs"*) or shovels (universal)	65	
Tapes (steel, 100 feet, 50 feet, 25 feet) ..	3	
Smiths' tools	3	
Trowels, masons'	6	
Spare helves (short and long)	80	

In addition to the above, 20 per cent. should be obtained as a reserve in case of unexpected delay in getting supplies, and other losses. If much rock is anticipated, more jumping bars or jumpers with sledge hammers are better.

Two smiths and two carpenters will be required to keep tools, etc., in order and execute minor repairs.

If the country is wooded, reduce the helves; if there are no trees, charcoal and small coal must be carried. Tools to which the native labour engaged is accustomed must be taken; for example, an African or Indian, if supplied with a wheelbarrow, would carry it on his head; therefore take baskets. Natives usually do not understand the use of the European spade, and, moreover, are usually barefooted; therefore obtain native "phourahs,"* *i.e.*, hoes, etc., which they can use.

Storekeepers have to keep a very careful check on the issue and receipt of all tools and plant, ropes, explosives, fuzes, etc. (for which purpose proper books should be taken). No issues should be made without a written voucher endorsed and filed for reference.

The selection of steel for pointing jumpers and picks requires care and practical knowledge; not every steel is suitable owing to variety of temper and qualities manufactured. Practical test beforehand is the best guide. Hard steel points will not be touched by a file; blue to straw colour of temper is best; if harder, the point may be too brittle.

Damage to tools is frequently due to careless supervision by allowing weaker tools to be applied where stronger are essential; for

* Mamootie is another name for the same tool.

instance, pickaxes and hoes, when used in place of crowbars and wedges for removing large stones and boulders, soon get destroyed; the lighter tools should only be employed against clays and gravels.

As regards other requirements, *e.g.*, compressed air plant for ingersoll drills, explosives, cordage, waterproof bags, timber for rafting, boats (collapsible), wire cable, huts and roofing material, tents, padlocks, "dogs," spikes, blocks, pulleys, crabs, various utensils, spare equipment, etc., the officer in charge must use his own discretion and forethought according to the circumstances.

ESSENTIALS—*for success in the construction of any road*:—

(1). Commence work at several places, giving preference to the most *difficult*, simultaneously, and connect up with a continuous path if possible.
(2). Set skilled masons and quarry men to work where rock cutting and blasting are required, so as to get stone dressed for masonry works, culverts, etc.
(3). Entire removal of vegetable soil and perishable material.
(4). Sub-soil drainage if the subgrade be the least soft.
(5). Roll and punn "formation surface," prepare "subgrade" and "crown" properly before laying a stone.
(6). Leave new embankments to consolidate for one season if possible, before completing foundation.
(7). Use unscreened stone chips to fill interstices.
(8). Exclude all clay and earth from metal, whether for foundations or top dressing.
(9). Sand or gravel to be clean for binding, and use only just enough.
(10). Water-sprinkle or swish in moderation when consolidating the surface.
(11). Roll thoroughly and slowly 30, 50, or more times.
(12). Leave for a few days before permitting traffic.

Avoid:—

(1). Round stones, especially in foundation.
(2). Clay, earth, or road-scrapings for binding.
(3). Large stones for surface; maximum 2 inches, better $1\frac{1}{2}$ inches; 1 inch when hand laid, and no rollers are available.
(4). Any admixture of soft and hard metal.
(5). Procrastination in tackling difficult places "till a more convenient season."

CHAPTER III.

MAINTENANCE, INSPECTIONS, PREVENTION OF DUST, ESTIMATES, ETC.

Maintenance.—Road maintenance means keeping the surface covering in such a condition as to fulfil the essentials given on p. 14. However well made in the first instance, every road requires maintenance in some form ; to do so economically and well demands close attention to principles, and careful scrutiny and study of the conditions and traffic prevailing at every mile of road, combined with constant vigilance by the roadmen and staff. Maintenance includes (i.) repairs ; (ii.), renewals. The one is quite distinct from the other.

The main principles to be followed are :—

(1). *Frequent* removal of mud or dust, which, if left, greatly assists deterioration by grinding action.
(2). Prompt *repairs* by the renewal of lost material.
(3). Complete *renewal* of the waterproof covering to the foundation *before* the surface has worn through.
(4). Efficient drainage.

Owing to the increasing loads of self-propelled traffic, and its extensive use of contributory roads (*i.e.*, other than main highways), many roads give out very quickly under modern traffic.

Road engines travel faster and with less steam over a road which has a good foundation than over one whose foundation is weak, or, in the proper sense, wanting.

Heavy traffic tends to displace the metal and squeeze the whole road into a series of corrugations ; the bulging of sidewalks, rising of haunches, displacement of gutters, and interrupted drainage are clear indications of an unstable, weak foundation and excessive weight of traffic.

When such roads were first made, nothing but slow and very light traffic was likely to use them, so that little money and less thought were given at the time to the three essentials for a good and lasting road, namely, a sound foundation, a waterproof and wear-resisting surface.

How to deal with the question is a matter engaging the attention of the road-maintaining authorities of to-day, and the problem is a difficult one.

To re-bottom the whole of the contributory roads throughout the

United Kingdom, to meet the increased weight and frequency of modern traffic, is an extravagant fancy; but something can be, and is being, done in this direction. . The designers of road vehicles, on their part, are endeavouring to improve the design of self-propelled wagons by making the driving wheels as large as possible, so as to reduce the intensity of load impact per square foot on the road subgrade and surface.

In Northumberland a few miles of road are being treated annually with success. The cost of providing a foundation varies from 11d. to 1s. 6d. per square yard, which includes labour, carting, etc., of hard whinstone, handpacking to 12 inches in the centre and 4 inches at the side, the natural subgrade being of clay; so considerable a thickness as 12 inches in the centre would not be necessary where the natural subgrade was harder. The saving in maintenance on a well-bottomed road is considerable.

Elsewhere a partial remedy has been tried with good results, namely, to cut out the weak "shoulders," or road haunches *only*, and relay, after putting in sound foundations, which act as abutments to the roadway covering of fresh metal filled in between them.

Experience, however, tends to show that if for a few years a little more stone of rather larger gauge is added to a road than is either usual or actually required to replace the annual wear, the requisite standard of strength can be attained with economy and efficiency.

One of the most promising and recent efforts in the renewal of roads is the method introduced by Mr. Arthur Gladwell, surveyor, of Eton R.D.C. The process is a waterproofing system, which will make a strong road of one whose foundation is not liable to destruction by water. It is fully described later, p. 105.

In tropical countries, where labour is very scarce in the wet season, as in British Central Africa, road maintenance has to be deferred until the end of the rains. This necessitates very large gangs working a short time. Two or three miles a day of earthen road can be repaired then by 500 to 600 men.

The cost of repairing a length of 100 miles of such earthen roads (see *Figs.* 26 and 27) works out at the rate of £4 per mile, 1,500 natives being employed under three Europeans.

The best roads in Europe are in France, Switzerland, and Italy, where an admirable system of maintenance and inspection, under a Government staff, is organized. Some of the roads in Austria and Spain are very well engineered and maintained.

In *France* each road is divided into sections, varying in length from a few hundred yards to several miles in some cases, but usually 1½ to 2 miles, according to traffic. Each section is under a labourer "cantonnier," whose duty it is to keep drains clear, roads scraped and cleaned, remove loose stones, break and stack metal for repair, trim the trees, and maintain the milestones, signposts, etc. (paint and whitewash them).

Six sections, forming a brigade, are under one foreman, "chief cantonnier." Several foremen are under one inspector. Several inspectors are under one engineer-in-chief in charge of the district, perhaps one county.

Wear.—The relative proportions in which a road surface is worn down from various causes is generally as follows:—

Atmospheric . .	...	...	...	...	20 per cent.
Wheel traffic . .	...	...	...	..	35 ,,
Animals' hoofs	...	...	...	...	45 ,,

The blows of a horse's hoofs produce considerable dynamic effect, and form depressions, which are soon enlarged by wheel traffic unless rapidly made good. At a walk a horse, drawing a heavily loaded wagon, does more injury than several horses drawing the same load in light vehicles at a quick pace.

The average loss of thickness in roads in Europe apparently does not exceed 1 inch per annum. In England, on main roads, the loss varies from 40 cubic yards per mile in the country to 1,000 cubic yards, and even 1,500, in the vicinity of large towns. The general average seems to be 70 to 80 cubic yards, and the least 10 cubic yards per mile.

In France and Austria the annual consumption of metal per mile to replace wear works out to 70 cubic yards.

Repairs.—Metal for maintenance is usually stacked in the "cess" at the roadside at intervals, the stack being so arranged that the cross section is constant and corresponds with a gauge containing an even number of square feet, so that by measuring the length and multiplying by the square capacity of the gauge the quantity of metal can be quickly assessed.

When repairing a *rut* the metal should be picked up and cleared out to a depth of 3 inches to 4½ inches, so as to leave it rectangular. This is then filled in with new material and *rammed*, water and gravel being added; it should be rolled and finished to a level surface, but not raised above the general contour.

Where, from unavoidable causes, three ruts or tracks have been formed, the material should never be put in all the three tracks at once, else fresh ruts will soon be formed between the rows of freshly laid stone by traffic avoiding them. It is best to fill up first the track made by animals' feet; they will avoid the newly-laid stone. As fresh tracks appear, first one wheel track should be filled, then the other. By judiciously spreading metal in small quantities, first on one part of the road and then on the other, the traffic is dispersed all over the road, the surface is kept level and hard, water runs off quickly, and there will be less tendency for ruts to form.

Renewals, as distinct from ordinary repairs, means re-metalling the whole width of road throughout or for any length, according to its condition and traffic.

Before applying any fresh metal, the existing road surface should be picked over, undersized metal and dust screened out, and the hollows filled up. The stone is scattered as evenly as can be from shovels, and rolled twice, dry, etc., as already described. See that gradients are preserved.

The best time for renewing roads is towards the end of the rainy season, but this may be carried out at any time, provided ample water is obtainable.

Metal broken by hand is usually more regular and evenly proportioned than that crushed by machinery, which pulverizes the stone and produces a superfluity of dust and fine stuff, which causes loose binding and a soft surface.

"Raveling," *i.e.*, when stones work loose on the surface, occurs after very dry weather, or from insufficiency of binding material. It can be remedied by sprinkling water or sand and re-rolling.

In *India* "kankar" is largely employed as a road metal, especially in the United Provinces.

It is usual to stack kankar for renewals along the roadside and leave it there for one year, so that all the earthy matter may be washed out by rain, and, moreover, to allow it to harden by exposure.

It is laid in the usual manner already described (p. 16), usually by hand, as steam rollers are seldom available. As good, if not better, results can be obtained by gangs of coolies working close together and ramming simultaneously with iron rammers. Simultaneous action is the chief thing, and this is usually effected to the strains of a monotonous native melody. Consolidation by heavy rollers drawn by bullocks is often resorted to.

In *Bengal*, where kankar is not universally available, overburnt or clinker brick is employed. This, if uniformly overburnt and hard, makes very good, smooth, dry roads, but they are not very lasting.

In *Bombay*, besides the igneous rock metalling employed on the large trunk roads and streets of towns, the most usual metal is "moorum," a kind of decayed igneous rock, having the appearance of a gravelly sandstone of reddish-brown colour; it is readily quarried by a pick, and easily broken under a hammer. It is found within a foot or two of the ground surface in the Deccan Tableland, and generally at the site of most roads. It is not so durable as other metal, and requires more care and attention; no sand or binding is necessary in laying or rolling it. The roller for consolidating should not exceed 10 tons, nor be less than 4 tons.

In *Madras*, *Burma*, and the *W. Coast of India*, on country roads for light traffic, where such are metalled, laterite is used; it is a reddish rock—consisting of silicate of alumina and oxide of iron—and is believed to be gneiss is an altered form, due to atmospheric agency extending over a long period.

It hardens on exposure to air and water, being quite soft when dug out. It is usually consolidated like "kankar" metal. Like "moorum," or any decayed rock, it is easily broken up, and makes smooth roads, but soon wears down.

It is a great mistake to repair roads, metalled with one kind of stone, with another of a different nature and texture.

At seaport towns in the East it is almost always practicable to obtain stone from ships arriving in ballast to load with rice, wheat, wood, or other cargoes.

Good binding, or "hogging," such as sharp sand, "bajri" (disintegrated rock, India), gravel, sandstone, and granite chips, is essential for ordinary metal, but it is certain to produce *dust*.

Every foreman should have a proper supply of tools:—Picks, shovels, spades, hoes, rakes, rammers, barrows, billhooks, scrapers, brooms, hammers (various), metal gauge, contour template, straight-edges, level and plummets, pruning knives, axes, and saws.

System and Chart of Road Maintenance—*India*.—In India roads are kept up from Government grants, civil or military; or from local funds and taxes, imposed by municipalities.*

Such funds may be:—

Imperial military—for M.W.S. roads (Military Works Services).
Imperial civil—for provincial roads of the P.W.D.
Municipal—for roads in towns, within the municipal limits of any city.
Cantonment—under the Cantonment magistrate.

N.B.—In every office there should be a register and chart with a corresponding plan of the roads, their **true lengths** *being marked thereon.*

On the tracing or map these roads should be shown by distinctive colours, according to the grant from which they are repaired, so that no confusion may arise. As a rule, a Garrison Engineer, R.E. (M.W.S.), is only concerned with Imperial military, except on the frontier, and sometimes with the Cantonment fund roads.

On the same map there should be Tables for each road, divided into sections of varying length, the object being to distribute the metalling of long roads over two or three years, according to the traffic, so that the sum to be expended on "renewals" may be fairly equally apportioned every year, and not fall heavy on one year and light on another (*Plate* IV.). In other words, a certain length of life is assigned to sections of a road between "renewal periods."

In the Peshawar district the life of road metal varies from three to seven years; a new coat, 3 inches to 4½ inches thick, is usual.

* *Vide Army Regulations, India*, Vol. XII., para. 58.

The areas in rectangles should be drawn to scale, so that the length, breadth, and superficial area of each section can be seen at a glance and estimated (see *Plates* IV. and V.).

As metal is collected on a certain section, broken and stacked during one season for consolidation the next, the corresponding rectangle can be coloured in to indicate "collected metal," ready stacked on that particular section.

Stacks of metal are usually dressed to a height of 18 inches, and of cross-section equal per foot run to the cross sections of metalling to be renewed, *e.g.*, for a 24-foot road, 9-inch thickness of coating, the cross section would be a trapezoid 18 inches high, 4½ feet top width, 7½ feet base width per foot run of road, stacked *both* sides.

After consolidation this coloured rectangle is hatched over, to indicate that that length was "consolidated" and renewed during that season.

By carrying out this system year by year, the proper period of *renewal* for each portion, and what sections are due for treatment, can be noted at once by referring to the register, which shows the "life" of each road or section of a road.

The register contains the quantities for every section worked out in detail, so that anyone called upon to make out an estimate for "renewals" of metal can do so by inspection of the map and the register, merely requiring to abstract and price the quantities.

Over and above *renewals*, a certain proportion must be added on account of *petty repairs*, *i.e.*, patches, hollows, ruts, etc., clearing ditches, pathways, trimming berms and hedges. To prevent hasty collection and delivery of inferior material, metal should be stacked and measured a year before required. It will usually harden and get cleared of earth by exposure to weather.

Cost of Maintenance.—This is a very variable and somewhat indeterminate quantity for extensive application. Conditions of climate, soil, metal, traffic, and price of labour and material are so different that mere comparison may be misleading. Useful deductions can be made, however, from records of *traffic* in each locality, which is the *ruling factor* in every road. Each locality should be dealt with on its own merits and conditions.

Unmetalled, transfrontier cart roads near Peshawar (India) cost to maintain £6 10s. to £12 10s. per mile per annum.

In Africa the chief item in the cost of road maintenance is the labour, and this varies considerably. In West Africa a native labourer receives about 5s. a *week*; 2s. is paid at the end of each week, and the balance, 3s., when he is discharged; say 100 men, £100 per month.

In British Central Africa and Rhodesia the native labourer receives 3s. a *month* and 6d. a *week* food money; say 100 men, £25 a

month. He is usually engaged for three months, and receives his deferred wages as in West Africa. Stores, tools and plant, salaries and allowances of European staff are costly.

Some authorities consider that £100 per mile per annum is an average cost at the present time (1908) for urban and rural main roads in England and Wales; in Ireland it runs as low an average as £14. Of recent years, consequent upon the demands of modern traffic, the annual cost has greatly increased from what it was. By way of comparison:—

Taking urban and rural roads together for the year 1895–96, the *average* cost of 25,650 miles of main road was £68·34 per mile. Ten years later (1905–06) the corresponding *average* cost of 27,380 miles was £90·51 per mile, an increase of 30·55 per cent., and an addition of 1,730 miles of road.

As a rough apportionment, urban roads cost £140 per mile per annum; rural roads, £56 per mile per annum; byeroads and lanes, £28 per mile per annum.

As traffic is the ruling factor, any comparison except by the *yard super* is fallacious.

In close proximity to London the cost has risen at a relatively greater rate in the endeavour of the authorities to meet the altered conditions brought about by modern self-propelled traffic.

In cities macadamized streets cost to maintain 1s. 7d. (Liverpool, Brighton, Norwich) to 3s. 7d. per yard super in London.

"*Travel Units*"—In France careful observations are made by the Government engineers to determine the amount of wear in terms of the traffic. The traffic is expressed in "units" representing a horse harnessed to a loaded wagon; to reduce the other traffic to this unit, the following values are used:—

1. Each horse hauling a public vehicle or a cart loaded with produce or merchandise	1
2. Each horse hauling an empty cart or a private carriage	$\frac{1}{2}$
3. Each horse, cow, or ox unharnessed, and each saddle horse	$\frac{1}{5}$
4. Each small animal (sheep or goat)	$\frac{1}{30}$

In 1876 the average amount of material required for the Routes Nationales was 53 cubic yards per mile per 100 "units" of daily traffic, the range for the different departments being 15 to 265, but usually from 27 to 102. In 1893 the average was 49 cubic yards per mile per 100 "units" of travel, the stone having an average co-efficient of wear of 10·85.

There are more than 338,000 miles of stone roads in France, which is equivalent to 1 mile of road for each 0·66 square miles of area, or 1·52 miles of road per square mile, and to 1 mile of road for each 119 inhabitants. The average cost of maintenance per mile is about £46 10s. per square mile of area, and about 5s. 9½d. per inhabitant.

The following Table gives a summary of the annual expenditures for material and labour for the roadway proper :—

Outlay on Materials and Labour on the Roadway Proper in France.

Ref. No.	Class of Road.	Width in Ft		Length, Miles.	*Annual Cost of Maintenance.		
		Right of Way.	Metalled.		Total.	Per Mile.	Year.
1	National Roads ..	66	22	22,009	£1,027,800	£46 7	1893
2	Departmental Roads .	40	20	16,188	£582,300	£36	Average 1886 to 1888
3	Provincial Roads .	33	20	128,522	£3,299,000	£25·6	
4	Communal Roads .	26	16	155 084	£1,768,400	£11 4	
	Total	—	—	321,803	£6,677,500	£20 75	

Maintenance Cost—France.—The following are some of the details of the cost of maintaining the national roads of France during 1893 :—

Number of miles	22,009
Average travel in 24 hours, "units"	170·6
Average amount of broken stone required (including 7½ per cent. of binding gravel) per mile per 100 "units," cubic yards	49
Average quality of stone, *i.e.*, average co-efficient of wear	10·85
Average cost of stone, per cubic yard	4s. 10½d.
Average cost of binding gravel, per cubic yard . .	1s. 6d
Average labour cost per cubic yard of material used	2s. 7½d.
Average wages of roadman, per day	2s. 3½d.
Average cost per mile per 100 "units" for materials	244s.
Average cost per mile per 100 "units" for labour ...	128s.
Total average cost per mile per 100 "units" for material and labour...	£16 12s.

In the department of Havre, France, the average annual cost of sweeping, removing mud, watering, and maintaining all works is as follows :—For departmental roads in the cities, 1½d. per square yard; and in the country, 1d.; and for communal roads, ½d. per square yard.*

The "Routes Nationales" of France approximate in their length to the urban and rural main roads of England and Wales, the total length of which, by the end of March, 1906, was 27,380 miles. The "contributory" roads correspond to the remainder in character.

* From extracts, Rockwell's *Roads and Pavements in France*, p. 67, etc., quoted by Baker (*Roads and Pavements*, 1903), and other sources.

In England and Wales there are at present no less than 1,85(maintenance authorities (55 county; 825 urban; 970 count borough, town, and rural district councils). The introduction o a State Highway Department, under Government engineers, as i France, would doubtless tend to secure uniformity of construction maintenance, and control, resulting in better roads at a reduced cost

Roads in Spain.—In so far as the roads are concerned which ar constructed and maintained directly by the State, Spain is no behind other countries. There may be a lack of certain main roads but there are as many miles of road per square mile of territory a in France, and a greater length per thousand of population.

In 1860 there was a length of 20,667 miles of these main roads and there are now 45,915 miles; and the scheme, which is not ye completed, will cost more than £40,000,000. The State gradually takes over provincial roads. For the cost of constructing 1 mile o main road of the third class, it is possible to make 2 miles of pro vincial road for considerable traffic.

In the years 1895 and 1896 the average cost of construction pe mile was:—

For 1st Class roads	£2,020
For 2nd Class roads	£1,834
For 3rd Class roads	£1,574

For the third class it may be taken that the average cost o construction per mile, inclusive of the survey, is £1,611, bu absolute reliance cannot be placed on the figures for the first clas and second class roads, as the number of miles of road from whic the figures are deduced bears too small a proportion to the total length of those classes of roads in Spain.

The cost of *constructing* these main roads in Spain does not exceed that of the French national roads. The annual cost of *maintenance* does not exceed the French departmental cost.

The cost of maintenance per mile is given as follows:—

Annual Cost of Maintenance per Mile.

Type of Road.	1895.	1896
1st Class	£38 16s.	£35 4s.
2nd Class	£32 17s.	£30 5s.
3rd Class . .	£26 17s.	£24 5s.

Extract from *Minutes of Proceedings of the Institution of Civil Engineers*, Vol. 134 (1897–98), pp. 445–6.

Inspections should include examination and attention to the following during the construction and maintenance of roads:—

(1). Surface.
(2). Gutters to be kept clean and clear of weeds, which become breeding grounds for mosquitos.
(3). Catchpools, culverts, catchwater drains—see that these are cleared and trimmed before each rainy season.
(4). Bridges, culverts—soffits, parapets, and copings.
(5). Sundries—milestones, guardstones, signposts.
(6). Overhanging trees—and drips from same.
(7). Avalanche tracks and tunnels.
(8). Retaining and breast walls—joints, copings, foundations, aprons, etc.
(9). Landslips and subsidences—faults, etc.
(10). Springs or water catchments.
(11). Foremen's record books of daily road gangs.
(12). Metal stacks, registers, maintenance chart (see *Plates* IV. and V., and p. 95), stores, and accounts.
(13). Tools and plant.
(14). Draught animals, stables, huts, and other accommodation.
(15). Progress chart during construction.

A form of progress chart (*Plate* VI.), introduced by Lieut.-Colonel W. J. Dundee, C.I.E., R.E., to show the state of the work on a road during construction, is used as follows:—

The filled-in rectangles represent lengths of road completed, as regards excavation, during successive *weeks*, shown in the side columns. Mileage and names of contractors, or headmen of gangs, are indicated on the top of the chart.

A copy of this chart should be sent periodically to the superintending engineer, who can see at a glance how the work is proceeding, and gauge relative rates of progress.

Standing Orders for Roadmen.—A roadman must be at work, wet or dry. The following instructions are condensed mainly from those issued by the Road Improvement Association, 1, Albemarle Street, Piccadilly, London, W., which are admirable:—

(1). Fill up all hollows, ruts, and puddles at once with *chips* from the stone heap.
(2). Use "chips" for patching and all repairs in the summer months, and for binding newly laid metal.
(3). Never add fresh metal if, by cross picking, raking, and re-rolling, the surface can be restored to proper contour and condition.
(4). The rake is the most useful implement, intelligently applied; therefore keep at hand at all times.

(5). In repairing large patches extending over the whole width of the road, spread the central track first, and, after this has worn in, complete the sides in turn.

(6). Spread the bulk of the renewal metal before midwinter.

(7). In moderately dry weather, and on hard roads, pick up the old surface into ridges 6 inches apart; remove all large and projecting stones before applying a new coating.

(8). When *large* stones project on a road, do not pick out, but crush.

(9). Spread metal in thin layers—one stone deep—adding second layer after the first has been rolled in.

(10). Never dump unbroken, or unequally or partially, crushed metal direct on to a road to break up on the surface, but stack at the sides and fill into the barrows with large pronged forks, so as to leave the chips and siftings for "binding" the top surface for summer repairs.

(11). Rake over a new coat daily to break down ridges.

(12). When diverting traffic for repairs, remove all temporary obstructions at nightfall—large stones, blocks of wood, etc.—and light well.

(13). Hard metal should be broken to smaller gauge than soft, but not exceeding $2\frac{1}{2}$-inch ring, using rollers; 2-inch ring and smaller gauge metal and chips are required for patch repairs and consolidation *by hand*.

(14). Avoid any rubbish for "binding," *e.g.*, road scrapings, sweepings, sods, and refuse.

(15). Allow no loose stones, dust, or mud to lie on the road; both induce deterioration, increase wear and tear, and double maintenance cost. Clean the roads after heavy rain, so as to let them dry quickly; cart away the scrapings immediately, before the dust dries and blows back again.

(16). Induce water to flow quickly away from a road surface and side gutters.

(17). Inspect roads in *wet* as well as during dry weather.

(18). After completion of renewals, remove all loose stones to the stone heap for use next season.

(19). After continuous heavy rain, a few hours should elapse before any heavy road engine traffic is allowed to travel over a road; the best road in the world will rapidly deteriorate if this is systematically disregarded.

(20). In spring time, after the frost is past, the road bed is soft and porous; thorough rolling at this time, with the addition of a little fresh road metal, is very beneficial and economical of maintenance.

(21). Lop and prune tall hedges and overhanging trees at the "fall" of the year where the road surface remains damp, so as to allow the wind and sun's rays to dry and harden it. Remove from the road all hedge trimmings, sticks, and thorns.

A type of "Standing Orders and Specifications for Road Maintenance, M.W.S., India, Plains and Hills," is given in full detail as Appendix C, to which is appended some Notes on Arboriculture, Felling of Trees, etc.

Prevention of Dust.—With the introduction of self-propelled traffic this is becoming a world-wide problem; dust is the greatest evil which motorists have to contend with, and, moreover, it causes much annoyance to the public, is a possible danger to health, and increases the road maintenance bill in every community. Hitherto no universal remedy has been found to mitigate the evil

"Summer dust makes winter mud"; it is more costly and laborious to remove mud than dust, therefore deal with it in summer.

Bass brooms do not displace stones so much as scrapers, and are more efficient; horse-sweeping machines are most effectual for keeping roads clean and dry.

Production of dust and loss of material from mere "weathering" is small as compared with the grinding action of animals' hoofs and vehicular traffic, drag brakes, etc. (see p. 93). The "dust nuisance," as distinguished from "dust production," is mainly due to swift and recurring traffic and the power of certain vehicles to raise dust a few feet higher than usual, whereby it is carried further and is more in evidence.

The dust is there; the motor vehicle tends to suck it up, and at the same time to cause small pieces of metal to work loose; the binding gets shifted, and the following traffic completes the mischief.

The difference between the damage done to roads, in the case of horse-drawn and self-propelled vehicles, whereby dust is produced from the actual road surface, is largely due to the fact that in the latter the propulsive power is applied through the tyres instead of through the horse, and the great power applied through the wheel driven has a churning effect, which is very destructive to the road surface. The tendency is for each road engine and motor to carry its own heavy load, and not drag the same weight, distributed over a trail of lightly loaded trucks; the wearing load is thereby much reduced (see Appendix D, Renard Motor Road Train).

Further, the thrust of a large-diameter wheel tends to displace the road metal *less* than does the thrust of an equally-loaded small one, the road being the fulcrum about which the turning moment takes place.

The remedy lies deeper, namely, in the materials of which both roads and wheel tyres are made.

So long as limestone, flint, gravel, and suchlike friable dust-producing metal is employed, and iron-tyred vehicles run with drag brakes and skidding wheels, the dust nuisance will remain; whinstone, granite, and other igneous rocks are less objectionable, but some other ingredients than sand and gravel are necessary for "binding." As a rule, far too much "binding" is used in making roads; the larger the proportion to metal, the greater the dust which will be produced.

So far as the roads are concerned, the solution of the problem lies in the careful selection of good, sound, suitable metal, seasoned with tar, and carefully laid with a minimum of binding of fine granite screenings, and a cautious extension of tar treatment of the road surface in *dry* weather.

It is possible that a remedy may be found in laying a substratum of rather rich tar concrete first of all, hard metal and binding being then spread over this, and the whole rolled until the tar grout rises to the surface, and left to dry a few days before allowing traffic.

Improvement in the design of motor vehicles, and in the method of street cleansing and scavenging at more frequent intervals will greatly assist. The substitution of resilient rubber-tyred vehicles for iron-tyred, and the gradual elimination of the cart horse, combined with more scientific road construction, will eventually bring about comparatively "dustless" roads.

Treatment of Existing Road Surfaces.—As it is impossible to change completely the character of existing road surfaces, their improvement by the application of some treatment claims attention at the present time, whatever may be done in the future.

The remedies applied so far fall mainly under three heads:—

(i.). Various oils, patent fluids and preparations.
(ii.). Spraying or painting with tar.
(iii.). The employment of special binders.

(i.). *Various Preparations.*—Loam and clay roads are improved by a *little* moisture—just enough to keep them damp. In hot climates there is usually much dust, and the road surface tends to ravel and wear into pot holes or very deep ruts.

Crude petroleum has been employed on roads in California instead of water, and on a number of railroads to reduce the dust; it has a further advantage in mitigating the glare by imparting a dark colour to the surface, and of preventing dust coating the foliage of trees and shrubs.

The oil used is the residuum after commercial oils have been distilled, and it contains about 17 per cent. of bitumen. It appears to be beneficial to macadam roads, as by aiding the road surface to

shed rain the tendency of mud to form is reduced, but drainage from crude oil poisons fish where discharged into streams.

The oil should be applied freely at 200° F. from a sprinkling cart when the road is quite dry; it must be thoroughly incorporated with the dust, and not merely sprinkled on the surface.

Three-quarters to 1¼ gallons per square yard for a first application, and less for a second. If properly done, only three sprinklings during the summer are found necessary (California).

The effect is best on a clay or gravelly loam, but it is ineffective on sand or an alkali soil.

In Baku, the centre of the oil industry in the Caucasus, the city is very dusty, but the roads at the oil wells on the outskirts are practically dust-free, through being saturated with the crude and abundant residue.

Petroleums having an asphalt base are best; the presence of paraffin and other mineral oils is detrimental to rubber tyres, owing to their solvent action.

Various patent palliative fluids, such as "Calcium Chloride," "Westrumite," "Akonia," etc., etc., have been used, but at best they can only be considered temporary remedies.

(ii.). *Spraying or Painting with Tar.* — Treating roads with *distilled* tar, or some preparation of tar, applied *hot* to the clean-swept surface, is effective and economical. For ordinary macadam roads tar seems to present the best remedy. Before applying tar the road surface should in the first instance be swept clean, and to this end may be cleansed with water, choosing a *hot dry* day for the purpose. Excess of moisture is deleterious to the life of tar. Crude tar from gasworks needs to be well refined to remove certain volatile oils, ammoniacal liquor, and water, which lowers its boiling point considerably. It should have a specific gravity of 1·24, and be heated to about 400° F., so that when applied it will be still very hot, and be well and *evenly* brushed in or "sprayed" over the road surface.

N.B.—*Crude* tar will produce a "sticky" road, and, after rain, water splashed up will stain fabrics; it is also said that surface drainage from roads treated with *crude* tar discharging into streams is destructive to fish.

Hence the necessity of applying properly *refined* tar, from which detrimental ingredients have been removed.

As a rough estimate, about 2 to 3½ lbs. of tar per square yard is required. The road surface must be *quite dry* before application.

Granite siftings should then be sprinkled from shovels over the tar. Cost of treatment varies; 2d. to 3d. per square yard of road surface is a fair estimate; a mixture of 1 lb. pitch to 5 gallons tar acts well.

Considerable attention is being given at the present time to the introduction of some mechanical appliance for spreading some

preparation containing tar and getting it to penetrate the road surface without rendering it sticky and offensive.

Something of the nature of an ordinary watering cart is required, provided with furnace and steam coils for boiling distilled tar; in addition some mechanical atomizer and spreader, or series of syringes, is needed which will force the tar in fine spray or jets into the surface.

As a result of recent competition and experiments carried out in May, 1907, under the auspices of the Roads Improvement Association and other bodies, various tar-spreading machines are now on the market. The best known are the Aitken Pneumatic Sprayer and the 700-gallon Thornycroft Motor Van of "Tarspra," Ltd.

N.B —The Johnston Lassailly machine puts on a heavier coating of tar, but is cumbersome and a little more costly to work.

It is believed that the cost of "spraying" roads with these machines need not exceed £1 per mile on an 18-foot road, exclusive of cost of tar.

The best preparation of tar was found to be Clare's tar-compo "Improved Dustroyd." Applied by a "Tarspra" machine, at the rate of one gallon to 7 square yards, in two coats, the quantity required to spread an 18-foot road works out at £26 per mile inclusive—the prime cost of the compo being about 3½d. (London).

"Tarvia" is another preparation which sets rapidly, and is extremely tough.

(iii). *Special "Binders."*—A most successful method of producing lasting and dustless road surfaces is that devised by Mr. Arthur Gladwell, engineer and surveyor to the Eton R.D.C., in collaboration with Mr. G. W. Manning, engineer and surveyor to the Staines R.D C. It can be applied where an existing road has to be re-surfaced or a new road constructed.

The process consists in spreading over a prepared foundation, brushed clean, a "bituminous sub-binder" or matrix "cushion," ½ inch to ¾ inch, composed of clean dried granite chippings (¼ inch), heated and mixed with "tarvia," a proprietary article of prepared tar—1 cubic yard covering 46 yards super. N.B.—Crude tar is quite unsuitable.

Ordinary stone metal, *clean*, aggregate 2-inch to 2¼-inch gauge, is then spread lightly and evenly with forks over this sub-binder, leaving an end width of 6 inches exposed to overlap and join with the next length.

N.B.—1 ton of metal, 2-inch gauge, is reckoned to cover 11 to 12 yards super with a 2-stone coat about 3½ inches in thickness.

Employing a light roller, the aggregate is then rolled gently into the sub-binder, which in turn is drawn up to fill the lower voids of the aggregate by consolidation, without any crushing. A little of

the sub-binder may be "salted" over the surface into any remaining voids; the rolling is then continued until the new surface is compacted.

The last stage is the "sealing" of the surface with some tar preparation to prevent access by moisture to any part of the coating. This may be done—*only in dry weather*—with "tarvia" or other compo, by a "Tarspra" or other mechanical spreader, or by hand. One gallon "tarvia" to 4 or 5 yards super will suffice. Finally, after spreading some more granite chippings of the sub-binder (1 ton per 150 yards super), the road should be well rolled and compacted. Cost of sealing about 2d. per yard super.

No sand, earth, or foreign matter should be allowed to reach the surface until this "sealing" is complete; the materials used must be quite clean and free from dust.

The cost—1s. 6d. per yard super—is found not to exceed that of ordinary renewals with granite metal, using water and sand "binding" (productive of much dust), by more than 3½d. per yard super.

The resulting surface is very satisfactory, both as regards wear and being non-dust-producing; moreover, it can easily be taken up and replaced to admit of repairs to water pipes, hydrants, etc., when the surface has to be broken.

A pamphlet (6d.) giving a full descriptive specification and further details of the Gladwell process can be obtained from the Roads Improvement Association, 1, Albemarle Street, Piccadilly, London, W.C.

Estimates, Specifications, etc.—As in maintenance, the first cost of roads is influenced by many factors.

Of all estimates which an engineer may have to submit, a mountain road is perhaps the most difficult to forecast with accuracy, especially when the road extends for many miles in a new or unopened country.

It is unwise to rely solely on statistics or comparison with other roads constructed under *apparently* similar circumstances and conditions.

Roadmaking in tropical Africa is very different to road work in Central India; the absence of skilled labour, transport, and good building materials, which will withstand the ravages of white ants, will considerably enhance an estimate for a road in tropical Africa, if based on experience gained in India.

In general, when roadmaking between plains and high and extensive mountain masses—like the Himalayas—the higher ranges, being composed mainly of hard rock, present fewer real engineering difficulties than the softer soil of the lower hills, formed geologically in all probability by the denudation of the higher.

The care with which useful information has been noted during the preliminary survey, and the prospecting has been carried out, will largely influence the estimated forecast; therefore the notes should be ample, and the members of the prospecting party observant, specially selected, and well informed.

Subheads of an Estimate.—The following is a useful list of subheads for a road estimate :—

1. Surveys and clearing site.
2. Surface drainage, preparation of subgrades.
3. Bridge sites and crossings, and masonry works.
4. Foundation and road surface.
5. Incidentals.—Fencing, parapets, and sundries
6. Rest houses and road gang depôt and stores.
7. Tools and plant.
8. Maintenance.
9. Pay of prospecting and engineer staffs, etc.
10. Abstract of total cost, and cost per mile.

Specifications.—Every* specification should embrace information on the following points :—

1. Description of the work.
2. Extent of the work.
3. Excavation.
4. Quality of material
5. Tests of material.
6. Delivery.
7. Preparation and character of foundation and road-bed.
8. Class of workmanship and defective work
9. Manner of execution.
10. Period and time of commencement.
11. Suspension of work.
12. Time of completion.
13. Method of payment, inspection, and measurements.
14. Penalties and extension of time, dismissal of workmen, strikes, etc.
15. Special clauses *re* rights to build sewers, lay pipes, cables, etc., accidents and liability for workmen and loss, etc.

For repairs and renewals the following should also be included :—

16. Removal and disposal of old materials.
17. Adjustment of manhole covers, kerbs, water tables, etc.
18. Supply and fixing of new kerbs, etc.
19. Concrete.
20. Pavement, character, quality, and laying.
21. Clearing up on completion.

* (Reference in part Byrne, pp. 557 and 585).

22. Clauses *re* traffic, accidents, damage, legal liabilities, lighting, and watchmen, etc.
23. Maintenance after completion.
24. Special stipulations.

NOTE.—See also p. 93 *et seq.*, and Appendix C for further details.

Computation of Earthwork.—For all practical purposes the approximate method, viz., to average the cross section from end areas, will suffice, but this will *always* give more than the true contents; or to employ Tables for *level* cross sections, which will give 3 to 4 per cent. excess.

For more accurate computing the prismoidal formula and method is employed, viz.:—One-sixth of the length × [sum of the 2 end areas + 4 × middle area] (see *Molesworth's Pocket-Book*, pp. 77–78, etc., edition 1904).

Figs. 81 to 87 represent cross sections with varying surface slope; the corresponding formulæ giving values of area are:—*

Fig. 81 . . . . . $A = \frac{H}{2}(L + B)$,

Figs. 82, 83, 84.. $A = L \times \frac{H}{2} + \frac{B}{2} - \frac{(d_1 + d)}{2}$,

Fig. 85 $A = \frac{1}{2}\left(\frac{B^2}{\cot x - \cot y}\right) = B^2 K$,

Fig. 86 . . $A_1 = \frac{(l_1 + a)\,d}{2}$ = area of larger triangle,

Fig. 87... $A_2 = \left(\frac{l_2 - a}{2}\right) d_1$ = area of the smaller triangle,

where AB = L,
DE = B,
CF = H,
FO = a,
EH = d,
GD = d_1,
PB = l_1,
AM = l_2,
x = angle of natural slope with horizon,
y = angle of side slopes,
s = ratio of slopes usually 1½ to 1 = cot y,
L is the horizontal projections of AB.

Values of K, etc., are given in *Molesworth's Pocket-Book*, p. 78 (edition 1904).

N.B.—These formulæ do not apply to cross sections of extremely irregular shape. In *Fig.* 87 the points C and F coincide, *i.e.*, there is neither cut nor fill; the triangles are similar, ∴ apply formula as in *Fig.* 86.

* Byrne—*Highway Construction*, p. 365.

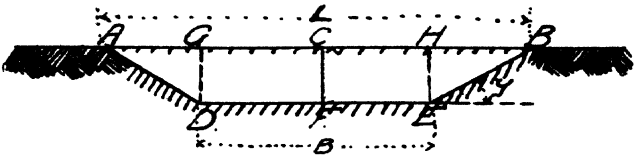


FIG. 81.

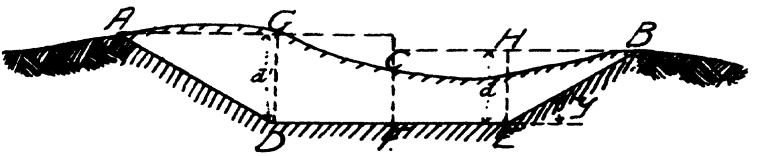


FIG. 82.

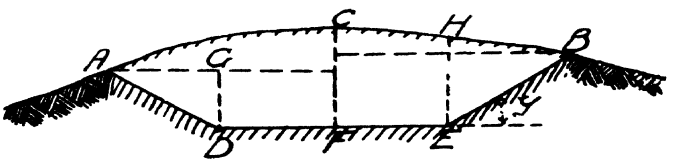


FIG 83

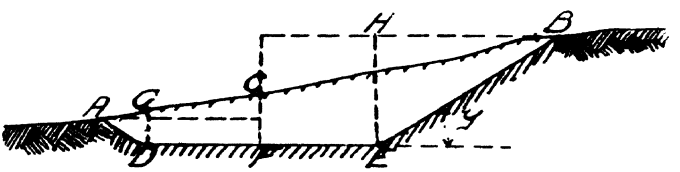


FIG 84.

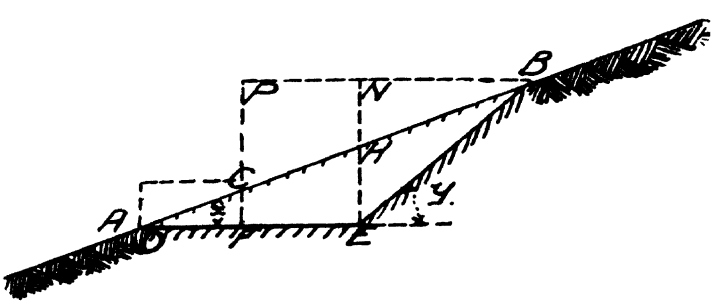


FIG. 85.

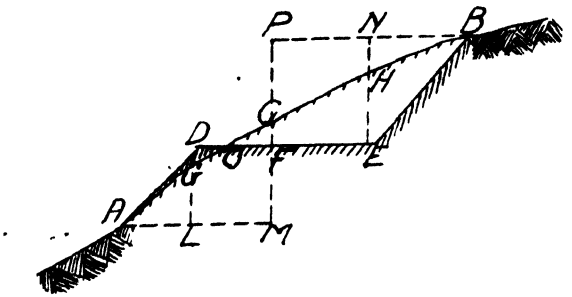


FIG. 86.

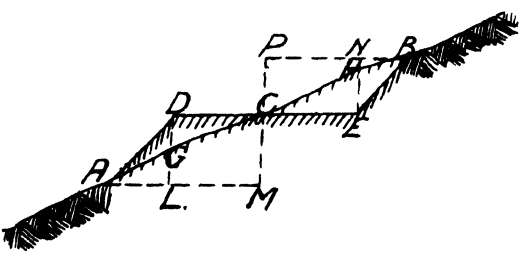


FIG. 87.

Where the number of areas to be computed is considerable, the contents may be arrived at by the use of Amsler's planimeter.

To set out the side widths of a road in sidelong ground and compute the earthwork can be done with sufficient accuracy for all practical purposes as follows :—On the plotted cross sections lay off the road width and side slopes, whether in bank or in cutting or both (*Figs.* 85, 87). Compute the half-breadth of the road ; it is required to find the points A and B (*Fig.* 87) on the ground ; this is done by trial and error with a level and staff.

Approximate the position of A ; find difference in level between A and C ; multiply this difference by the ratios of the side slopes, and subtract the result from the computed half width. If the remainder equal the distance of the staff from the centre line, the position assumed for A will be correct ; otherwise repeat till correct. If the remainder *exceed* the distance of the assumed point A to the centre line, the point is too near ; and *vice versâ*. For B proceed in the same way.

In the case of an embankment there is no difference in procedure.

In computing earthwork in the field it is a great saving in time and more conducive to practical accuracy if this can be done on the spot as alignment and tracing proceeds ; nature of soil can be recorded for each length, priced and estimated on the spot.

The following method, introduced by Capt. H. S. Rogers, R.E.,

when prospecting for roads for pack animals in the hills in India, has much to recommend it.

It affords a simple method of recording the quantity of cutting (especially for narrow roads on steep ground), and does away with the necessity for cross sections. It was found especially valuable in arriving at the comparative probable costs of alternative alignments (see *Fig* 88).

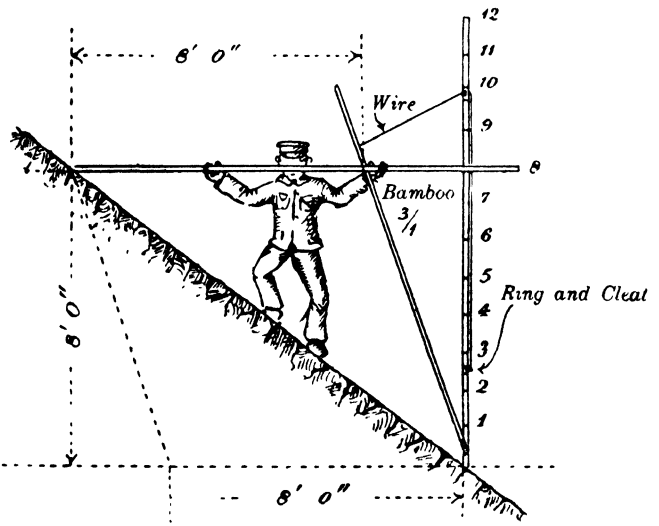


Fig 88.

Assuming that the outer cutting edge is run with the clinometer and marked out.

Chaining is commenced at the top, the computing party, provided with a slope template, working with the back chainman.

The template is used for setting off the estimated back slope on which the area of the cutting largely depends; it consists of a stout vertical batten ($2\frac{1}{2}'' \times 2''$) graduated in feet, and provided at the foot with a hinged or knuckle joint, into which is fitted a long light bamboo. To this bamboo arm a wire is attached, which passes over a pulley in the batten and ends in a ring for hooking over screws or cleats, placed so as to enable the arm to be set at slopes, with the batten placed vertically, of

$$\frac{1}{1}, \frac{1\frac{1}{2}}{1} \ldots \text{to (say)} \frac{4}{1}.$$

To use it the template is set up by one man on the spot fixed by the back chainman. A second with a long straight bamboo, marked

at 4 feet, 6 feet, 8 feet from one end (*i.e.*, the widths for the cuttings), and standing on the slope above the template, places one hand at the mark given (in the cases referred to usually 8 feet full cutting for a mule road); he then holds the bamboo high and horizontal, with his hand against the movable arm, lowering the rod—maintained horizontal—until the end touches the ground slope. The height is then read from the vertical rod, and recorded, together with the area of cutting and the quantity under the soil column.

It then only remains to total and price the work at the end of the day.

The field book is ruled thus :—

Chain (100 ft.)	Back Slope.	Width.	Height.	Superficial Area.	Soil in Cubic Feet			
					Hard.	Medium	Soft.	
			Brought	forward	10,270	18,900	25 460	
19	3/1	8 feet	6 feet	24	—	2,400	—	
20	2½/1	8 ,,	4 ,,	16	—	—	1 600	About half hard.
21	3/1	8 ,,	8 ,	32	1,600	1,600	—	Spur at 21·8.
22	2/1	6 ,,	5 ,,	15	—	—	1,500	Allow 2-foot bank.
			Carried	over ...				

In the remarks column entries can be made where streams are crossed, length of Irish bridges and culverts, etc., etc., can be noted, and any special points regarding the soil and excavation required.

Sufficient accuracy can be usually attained by dividing the work and prices into *hard*, *i.e.*, soil requiring blasting; *medium*, *i.e.*, requiring blasting and jumper work; and *soft*, or pick-and-jumper work.

Various problems and solutions in Earthwork Measurements are given in *Henck's Field Book for Railroad Engineers*, pp. 92–114 and 135. Reference may also be made to Rankine's *Rules and Tables*, p. 145, and various Earthwork Tables, *e.g.*, Macneill's and Bidder's.

An adaptation of Bidder's *Earthwork Tables* is given at Appendix E.

Approximate Cost of Roads.—The following data have been collected from various sources, and give a fair guide for this purpose :—

Earthen Roads (India) (*Fig.* 23)... .	£10 to £50 per mile.
do. (America), 30 feet wide, 18 feet roadway, covered with 9 inches of clay or earth*†	£500 to £900 ,,
do. (British Central Africa) 20 feet wide (*Fig.* 27)	£10 ,,
do. (Northern Nigeria and West Coast of Africa—exclusive of bridges)	£40 ,,

ENGLAND.

New Road, 45 feet over all, including footpaths, kerbs, sewers, channels, etc., complete† ...	£8,400 ,,
do. do. 36 feet wide‡	£7,040 ,,
do. do. 24 feet wide, carriage way only	£3,080 ,,

§ *Public Thoroughfares* and streets with all accessories, 12-inch foundation, 7-inch metalling:—

40-foot road	£8,000 ,,
36-foot road	£7,100 ,,
30-foot road	£5,720 ,,

High Road—exclusive of footpaths, sewers, etc. 10-inch foundation and 7-inch metalling:—

30-foot road	£3,520 ,,
24-foot road	£2,820 ,,

Light Roads—exclusive of footpaths, sewers, etc., 6-inch foundation and 4-inch metalling:—

30 foot road	£2,640 ,,
24 foot road	£2,120 ,,

Mountain Road—(Cumberland); 18 feet width; maximum grade, 1 in 12; no heavy work; road of light character ... ... | £1,430 ,,

INDIA.

Macadamized Roads, 2nd Class:—

12-foot roads (plains), including banks, cuttings, bridges, etc.	£150 to £200 ,,
12-foot roads (hills)	£450 to £500 ,,
16-foot roads (hills)	£500 to £800 ,,

* £1 reckoned equal to 15 rupees, or 4·8 dollars.
† Byrne, p. 488.
‡ For detail item see p. 117.
§ Coleman's *Pocket-Book of Approximate Estimates*, 1907.

Macadamized Roads, 1st Class:—

18-foot road (hills), including banks, cuttings, bridges, etc., with precipice work	£3,000 to £4,000 per mile.
do. do. no precipice work, no large span bridges	£1,500 „
20 foot road (plains) easy work . ..	£600 „
do. do. including culverts, etc., but no large span bridges . .	£2,000 „
24-foot road (plains)	£1,000 „
30-foot road (plains)	£1,400 „

For rough estimates in a 16-foot road the following are approximately of equal cost (*Roorkee Treatise*, Vol. II., p. 215):—

Embankment, 4 feet high ...	1 mile.
Culverts (aggregate spans) . .	36 feet.
Large bridge	10-foot run.
Maintenance	300 yards.

Large span road bridges cost approximately £8 to £10 per foot run.

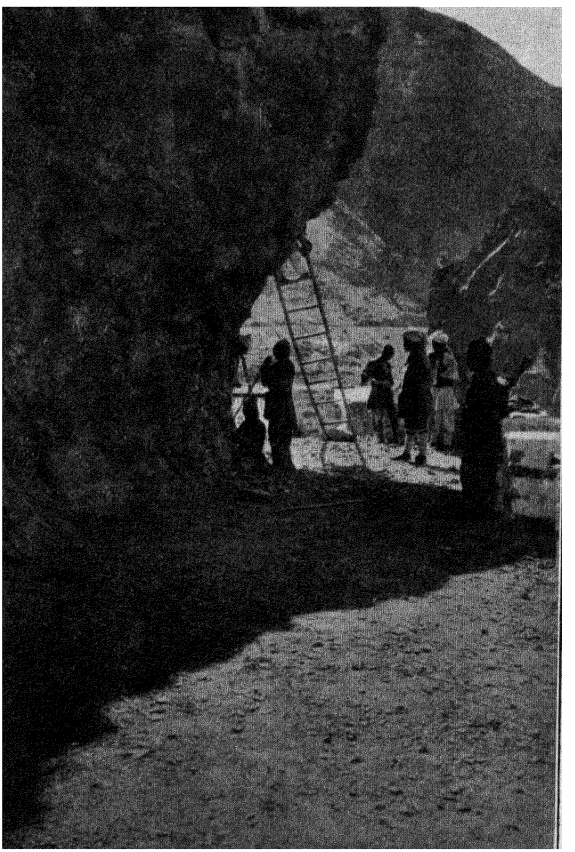
Metalling, where stone is plentiful, *e.g.*, hills, £300 per mile.

Approximate Estimates for Hill Roads.—If ordered to make a reconnaissance of a valley or pass for a road, the country should be examined for some distance on either side of the ordered route Not only will it sometimes be possible to introduce economical diversions, but it may result in the discovery of valuable material. All these points will affect the estimates. Very often, however, approximate estimates are called for at a moment's notice, with the least possible reconnaissance; the question then becomes one of considerable doubt and difficulty.

At every yard of road in a rugged mountainous region the local conditions of soil, drainage, etc., vary; the ground is often inaccessible, and the nature of the soil has to be guessed. Cost of excavation of different soils varies by something like 700 per cent., and as such excavation forms the greater part of every hill road estimate, a faulty guess may make an enormous difference in the total cost. This is more so than in railway estimates, because in the latter case so large a proportion of the cost is made up of permanent way, stations, rolling stock, etc., that an error in estimating the value of the earthwork has not the same importance. Once a road is commenced, everything depends on the careful watch, by the officer in charge, on expenditure, to see whether the actual cost is agreeing with the estimated figures as the work progresses.

It must also be remembered in *hill road* construction that the

cost varies as *the square of the width*; if a road is to be 8 feet wide, probably 4 feet wide in the hillside will suffice, the excavated earth making up the remaining 4 feet; a road 4 feet wide will only cost 25 per cent. of the price of the 8-foot road. Hence it is always



Mountain Road, India.—Hazaras Widening an Awkward Corner.

wise to make at first a narrow road along the whole alignment approved of, and then to widen it out as funds admit (see pp. 48, 86).

In roadmaking, the only safe way of working to an estimated cost without excess is by task work, *i.e.*, giving lump sums for

specified lengths based on estimated quantities, keeping in hand a considerable margin to meet the cost of extras, such as additional culverts, widening bad corners; building mortar masonry drop walls, clearing landslips, making good damage, and for sundry improvements; also for paying a "bonus" where time is an important factor.

When roads have to be constructed through country in the occupation of independent tribes, as in tropical Africa and on the Indian frontier, satisfactory results can usually be obtained by enlisting them as labourers, organized in gangs under their own headmen, who are made responsible; regular and prompt payments in *coin* are essential in such cases, to establish *bona fides* and maintain satisfactory relations between officers and road gangs.

Task work induces a healthy rivalry between gangs; lazy or poor workers will soon get discharged by the headmen or gangers.

The above methods facilitate supervision, save disputes over measurements, and promote good feeling with headmen and road gangers.

The officer in charge must be shrewd and careful in making his estimates and lump-sum contracts, otherwise he may find that he has paid high rates for execution of the easier lengths, and got them completed, leaving very little money for carrying through the more difficult sections (see pp. 49, 87). Monthly reports, showing progress, with mileage cost, afford a useful comparative scale between labour gangs and sections.

A road, 16 feet clear width, in the Khyber, Malakand and Kurram Valley (Indian frontier), unmetalled, for native cart traffic, should not exceed £700 per mile in the hill portions, *ex*clusive of bridges.

Such a road may cost for excavation alone anything between £250 to £1,600 per mile, *ex*clusive of retaining walls, bridges, parapets, and metalling.

A 6-foot path may cost, as above, £150 to £200. The continuation of the old Hindustan-Tibet road—an unmetalled mule track, 7 feet wide with gradients of 1 in 6 and 1 in 4—cost about £500 per mile.

The Chakrata Road, 18 feet, bridging light ..	£1,450	per mile.
,, Kangra Valley Road, 18 feet, bridging heavy, labour abundant	£2,080	,,
,, Dalhousie Road, 18 feet, excavation heavy, labour scarce	£2,400	,,

The above include metalling at £240 per mile.

The Amba Ghât Road (Western India), 20 feet clear width, cost £2,500 per mile, including bridge, culverts, metalling, but exclusive of the pay and allowances of the staff.

The proportions per mile were :—

Roadwork	£1,450
Masonry	900
Metalling	150
	£2,500

A road crossing a deep, wet, alluvial valley and ordinary undulating uplands (India), running parallel with and near a river, cost £800 per mile. (Roadwork, £160; masonry works, £460; metalling and surfacing, £180).

Blasting.—For precipice work allow 1 lb. of English powder per 150 cubic feet rock on an average; 75 to 85 cubic feet of granite; 110 to 115 cubic feet of limestone; 200 cubic feet of conglomerate, using very large mine *galleries*, cost 7s. per 1,000 cubic feet; with small blasts only, 24s. to 28s. per 1,000 cubic feet.

The Simplon Road (Switzerland), a mountain road—average width, 25 feet; steepest grade, 1 in 13—was largely blasted out of solid rock, and including 10 galleries or tunnels, with several heavy masonry terraces, cost £5,000 per mile.

Detail of Average Cost in England of a Thoroughfare 36 feet wide, including Footpaths, Sewers, etc. { *Carriage Way 24 feet wide.* / *2 Footpaths 6 feet wide.*

Description	Per Yard Run. s.	d.
Excavating and levelling for road 36 feet wide, removing surplus earth, etc.	9	6
Rubble stone underlay 12 inches deep, including laying and binding with broken material	13	0
Three inches of stone broken to 2½-inch gauge, 3 inches of granite metalling, 1½-inch gauge, and 1 inch of gravel and well rolling...	16	0
Footpaths 6 feet wide each side, formed with tar paving 3 inches thick, on foundation of broken stone 3 inches thick, including stone kerb and channel	18	6
Glazed stoneware sewers (up to 15 inches diameter), laid complete, including street gullies, manholes, digging in ordinary ground, filling in, etc.	23	6
Per yard run	£4	0 0
= per mile £7,040		

Detail of Average Cost of 24-foot Carriage Way, exclusive of Footpaths, Sewers, etc.

Description	Per Yard Run.		
		s.	d.
Excavating and levelling for road 24 feet wide, removing surplus earth, etc.		6	6
Rubble stone underlay 10 inches deep, including laying and binding with broken material		11	0
Four inches of stone broken to 3-inch gauge, 2 inches of granite metalling 1½-inch gauge, and 1 inch of binding gravel . ..		13	9
Steam rolling and watering		0	9
Per yard run .	£1	12	0
= per mile £3,080			

Extracted from Coleman's *Approximate Estimates*, 1907.

The following sundry items of cost, etc., may be found useful as a guide; they have been collected from various sources.

Earthwork and Metal.—Every 5 to 6 feet in cuttings beyond the first 6 feet in depth increases the price 36 per cent.

One ton of earth averages about 24 cubic feet; details for various earths are given in *Hurst's Pocket-Book*, pp. 192—5.

One ton of stone metal = 1 cubic yard or a little less.

One ton of granite cubes	$3\frac{1}{2}'' \times 3\frac{1}{2}'' \times 3\frac{1}{2}''$	will cover	$6\frac{1}{5}$	sq. yds.
,, ,, setts	$4'' \times 4'' \times 3''$	,,	$5\frac{1}{3}$	,,
,, ,, ,,	$5'' \times 3'' \times 3''$	,,	$4\frac{2}{5}$	,,
,, ,, ,,	$7'' \times 3'' \times 3''$	,,	3	,,
,, Kentish rag metal		,,	5 to $5\frac{1}{2}$	,,

One ton of Aberdeen granite represents about $13\frac{1}{2}$ cubic feet.

Broken metal, $2\frac{1}{2}$-inch gauge, contains approximately 55 per cent. solid stone, 45 per cent. voids and dust.

Metal Required.—One ton of $2\frac{1}{2}$-inch screened metal covers approximately a single stone thickness of 13 square yards of road surface. One ton of 2-inch clean metal will cover 11 to 12 yards super with a 2-stone thickness. One cubic yard of ordinary unscreened hand-broken stone, $\frac{1}{2}$-inch to $2\frac{1}{4}$-inch gauge, will, if carefully spread, cover double this area.

When spread close for steam rolling, the area covered will not exceed 15 to 16 square yards.

Wood Pavement.—Deal blocks 8″ or 9″ × 5″ × 3″ can be obtained in London for £5 7s. to £6 12s. per thousand.

Creosoting costs £1 per thousand.

Jarrah and Karri blocks 9″ × 5″ × 3″ cost in London £12 to £13 per thousand. 48 to 50 blocks cover a square yard.

Creosoted deal blocks laid on an existing concrete foundation cost about 9s. to 10s 6d. per square yard.

Creosoted Jarrah blocks laid on an existing concrete foundation cost about 16s. 6d. per square yard; if well seasoned, creosoting is not necessary, so deduct 1s. 8d. to 2s. less.

The above includes 4s. for laying.

For excavating and providing a 6-inch concrete foundation the above prices should be increased by 3s. 3d. to 3s. 6d.

Maintenance costs 7d. to 1s. per square yard.

Asphalt.—Roadway of hot compressed powder, punned, 2 inches to 2¼ inches thick and rolled with a half-ton roller until cool, 12s. to 13s. 6d. per square yard, with 4-inch to 6-inch concrete foundation; 10s. to 10s 6d. without (London); maintenance, 1s. 10d. per square yard per annum.

Asphalt powder, 1 inch, laid on 4 inches of concrete, 4s. 6d. per square yard.

5 cwt. of asphalt (mastic)—contents of a cauldron—will cover 7 to 8 square yards, ¾-inch thick, and will require 1 cwt. of coal as fuel to melt it.

Paving.—Of stone flags, 2 inches to 3 inches thick, laid upon a bed of earth, rubbish, gravel, or stone chippings rammed to 3 inches.

Foundation—4½d per square yard } say 5s. 6d. to 7s per square
Flags—5s. to 6s. 9d. per square yard } yard, according to locality.

Paving of granite setts 7″ × 3″—12s. 6d. to 13s. 6d. per square yard.

Paving of concrete, provided and laid—4s. 6d. to 5s. per square yard.

Paving of tar (as specified, p. 22)—1s. 9d. to 2s. per square yard, or less, according to locality.

Steam Rolling costs 8d. to 11d. per ton of metal; the fewer the stoppages and checks on account of passing traffic, the cheaper the rate. The quantity rolled per diem varies from about 500 to 2,000 square yards; 1,500 square yards is a fair average on an ordinary road.

The cost of maintenance of a 10-ton steam roller is about $\frac{1}{10}$th of the prime cost; referred to road surface, the cost varies between ⅓d. to ⅛d. per square yard.

Watering.—Road watering (municipal) in cities and large towns works out between 3d. and 4d. per 1,000 yards super, *in*clusive of all expenses and water, which represents half the cost.

Sundry.—Tar is sold in 36-gallon casks, price about 9s to 10s., and in barrels, 28 gallons, price about 7s. to 8s.

Tarmacadam.—The average cost of laying in various localities in England to an average thickness of 4¼ inches, inclusive of foundation, is 3s. per yard super.

"Tar mac."—3-inch coating on an existing road rolled to 2¼ inches, at Leicester, cost 1s. 7d. per square yard, *i.e.*, 6d. more than ordinary macadam.

"Tar mac" costs 3d. to 6d. per yard super to maintain, according to locality, when well and properly laid.

The Gladwell process applied to an existing road, 2-stone coat of metal (2 inches) overlaying a ½ to ¾-inch "cushion" of special granite chipping tar binder, and surface compacted and sealed with "tarvia," costs 1s. 6d. per yard super.

N.B.—Many useful items may be obtained from *How to Estimate*, Rae, 2nd edition, 1904. (Batsford).

CHAPTER IV.

WATERWAY—SCOUR.

WHEREVER a road or railway embankment is built to cross a very large area, whereby the natural flow of surface water becomes blocked, there is considerable risk of damage by flood waters, unless adequate waterway is provided for passing off the flood discharge. Equally with roads in hilly and mountainous country, the provision of waterways must not be overlooked. Culverts and waterways therefore require special attention. They should be made ample, yet not extravagant.

Definition.—A culvert may be any waterway from a 2-foot or 3-foot square opening, termed a "box" culvert, up to 15 feet, and larger spans, termed "arched" culverts, either single or in a series extending over several hundred yards. The size and number evidently depend upon the maximum quantity of water to be carried through during the heaviest flood.

Factors affecting Waterway.—The area of waterway to be provided depends upon :—

(1). The *maximum* rate of rainfall during severest storms and flood discharge.

(2). Permeability, or otherwise, and degree of cultivation of the soil.

(3). Character and inclination of the ground surface, influencing rapidity of flow.

(4). Condition and inclination of the bed of the stream, whether clear or obstructed.

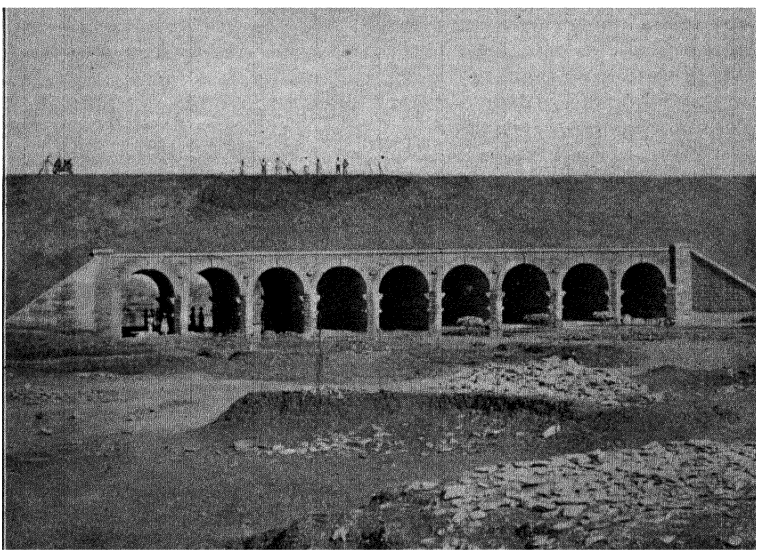
(5). Shape of the area to be drained.

For example, if the area is long and narrow, the drainage from the lower portion may pass through the discharge opening before that from the higher ground arrives ; again, if the higher ground is steeper than lower down, the waters may have to be discharged at one and the same time ; the number and locality of feeders also influence the drainage discharge. The shape of an area and locality of the water courses and feeders are of greater importance in large than small drainage areas.

(6). Form of entrance of the culvert and inclination of the invert.

(7). Whether an "afflux," *i.e.*, a banking-up of water before entry, is permissible, so as to discharge under a head.

N.B.—Maximum rainfall seldom exceeds 1 inch per hour = 3,630 cubic feet per acre. Only some 50 per cent. to 75 per cent. of this will ever reach a flood opening. Inches of rainfall × 2,323,200 = cubic feet per square mile.



Flood Openings—India.

Estimation of Waterway.—To determine the requisite discharge opening is not very simple; anyone can construct an extravagant number of culverts, and so be safe against any flood discharge, but consideration of cost constitutes the ruling factor in general. In the preliminary examination of a country there is a tendency to underestimate the small waterways, as much water that passes almost unnoticed through grass and scrub in flat districts, is concentrated by the construction of railway embankments, and forced to pass through defined and restricted channels; whilst, on the other hand, there is a tendency to overestimate those on large rivers, especially in the alluvial districts, where shallow channels traverse the river bed in irregular sinuosities, and these are forced into deep channels when concentrated by the construction of a bridge. Information given by villagers of the height of floods is generally very contradictory, and often unreliable, but the construction of an embankment generally tends, by concentration, to raise the water level above the highest flood on record. It is, therefore, desirable to give a good margin of headway. In some cases, where the bed of a river is dry for several seasons, it is difficult to distinguish the bed from the surrounding country.

The maximum flood discharge of a river must often be a matter

of great uncertainty, and it is very difficult to determine the maximum amount of water that has to be passed through at a given period. The method that naturally suggests itself is to ascertain the drainage area and the maximum rainfall from such records as may exist, and calculate the total quantity, making due allowance for absorption.

Several formulæ, based on the experience of large rivers, are more or less useful for the individual districts on which they have been based, but it is evident that such formulæ must be used with great caution, for no two localities present the same conditions. To cite two cases of entirely different character, to show how little dependence can be placed on coefficients depending upon a given catchment area or length of main drainage:—

At Cherra Punji the annual rainfall is somewhere from about 600 to 800 inches, yet at Shillong, only 30 miles distant, the rainfall is barely over 100 inches. The moisture-laden clouds, coming straight from the Bay of Bengal, pass over the moist warm country of Lower Assam, and suddenly meet a precipitous ascent, several thousand feet in height, and comparatively cold, in consequence of the great elevation; the result is a sudden condensation of the vapour, giving an enormous rainfall, but by the time the clouds have reached Shillong they have parted with much of their moisture.

The other case is that of the Guggur River, which has its origin in the Himalaya mountains. In the rains it is a broad but somewhat shallow river, about half a mile in breadth, with a current so swift that when in flood, it can scarcely be stemmed by an elephant; yet this river decreases as it recedes from the mountains, loses itself at last in the desert, never reaching the sea.

"*Afflux.*"—In determining the waterway, some curtailment of the natural opening is almost inevitable, because the safest width would, in many rivers, be inconveniently great. Therefore, if the net opening is somewhat restricted, it follows that flood water, confined to narrow bounds, becomes headed up, the level being raised above the bridge; this is termed the "afflux." Concurrently the velocity through the bridge is increased, and this velocity must not exceed that which the natural bed can withstand without scour resulting (see p. 138).

To determine the "afflux" (x) at any bridge opening:—

Let L = normal breadth of the stream.
l = net ,, ,, water openings.
c = a constant (usually ·9).
V = normal velocity of stream in feet per second.

$$x \text{ (feet)} = \frac{V^2}{2g}\left\{\frac{L^2}{c^2 l^2} - 1\right\}.$$

To this add 20 to 25 per cent. to obtain a closer approximation.

For example:—

A bridge of 4 openings, each 30 feet span.

Breadth of river, 150 feet (L); normal velocity of river, 8 feet per second.

$$x = \frac{8^2}{2 \times 32}\left\{\frac{150^2}{\cdot 81 \times (4 \times 30)^2} - 1\right\} = \cdot 92.$$

$\therefore$ corrected value of $x = 1 \cdot 15$ feet, say 14 to 15 inches.

The proper procedure to arrive at the correct size of a culvert or waterway is as follows:—

(A). *For Culverts and Small Bridges* measure the drainage area and make the opening large enough to carry off 3 inches to 4 inches of rainfall in 1 hour; or deduce from formulæ:—

NOTE.—Four inches an hour may appear excessive, but it will be quite safe. In the Kangra Valley, a very wet district, 5 inches per hour is allowed over catchment areas not exceeding 1 square mile.

Meyer.—

If a = area of opening in square feet (Baker, *Construction*, p. 394).
A = drainage area in *acres*.
C = a co-efficient – for flat prairie country 1
,, hilly ground .... 1·5
,, mountains and rocky ground 4

$a = C\sqrt{A}$.

N B.—For small drainage areas the result is too large.
For large ,, ,, ,, too low.

Talbot.—A more reliable formula, using the same notation.

$a = C\sqrt[4]{A^3}$ where C in steep rocky ground varies from ·7 to unity;
for rolling agricultural country ....·3.

In districts not affected by snow (accumulated), and where the length of the valley is several times the width, C may be $\frac{1}{5}$th or $\frac{1}{6}$th; increase C for steep side slopes.*

Chamier—using previous notation, and—

Q = maximum discharge at the outlet in cubic feet per second.
R = average rate of greatest rainfall, anticipated in inches per hour, for such duration as will allow of the flood water flowing to the outlet from the farthest extremity of the catchment area.
C = co-efficient of surface discharge, giving the proportion of rainfall which may be expected to flow off the surface.

Flat country, sandy soil, or cultivated land	0·25 to ·35.
Meadows, gentle slopes, and absorbent ground ...	0·35 to ·45.
Wooded hill slopes, stony, compact ground.....	0·45 to ·55.
Mountainous country, non-absorbent...	0·55 to ·65.
Bare mountains, paved surfaces	0·80 and over.

M = catchment area in *square miles*.

$$Q = 640\ CR\sqrt[4]{M^3}.$$

* Extracted originally from C.E. Club University of Illinois—quoted by Mr. Baker, and corroborated from practical experience.

The special characteristic of this formula is that it takes into account the duration of the rainfall; the average rate of fall varies inversely as the duration, which must depend on size and shape of the basin, length of principal water courses, and ground inclination. It has been tested by practical experience in N.S. Wales, Australia, *vide* Appendix F, p. 159.

*Dickens**—for estimating the maximum flood discharge in cubic feet per second (D) when M = drainage or catchment area in *square miles*—holds good for 24 to 50 inches average annual rainfall:—

$$D = 825\sqrt[4]{M^3}.$$

Tables of calculated results were published in 1899 as *Technical Paper*, No. 61, by the Government of India Press, Simla. Refer also to Marryat's *Specifications and Notes* (5th edition, 1902, Sprott), G. of I. Press, Bombay—Table XLII.

Hering†—using previous notation, and—

Q = number of cubic feet per acre per second reaching the culvert.
S = general fall per 1,000 feet.
R_0 = average intensity of rainfall in cubic feet per acre per second.
A = drainage area in *acres* = M 640.
C = a coefficient of discharge varying from ·31 to ·75, or taking ·62 for general use.

$$Q = CR_0\sqrt{\frac{S}{A}}.$$

It must be borne in mind, however, that the characters of areas are so different that some sort of constant must be applied to qualify any formula based on experience of the area in question, *e.g.*, something must be known of the conditions of forestation, denudation, hill slopes, presence of snow, local or general rainfall, heavy and intermittent, or light and lasting, etc., etc. (*Technical Paper*, 114, India, 1902).

Drainage in tropical countries should never be estimated from the floods, however severe, during the first month of the rainy season; after three months of parching, the earth readily absorbs a larger proportion of the first flood than subsequently when saturated; consequently the rainfall and floods later on may cause a greater discharge to be passed through the waterways.

Discharging capacities of channels of different form are to one another as their areas squared ÷ surface width.

In determining the area of a small waterway an error of 100 to 200 per cent. is of little consequence. The question virtually resolves itself into whether a 2-foot or a 3-foot *pipe*, or a 6-foot or 8-foot *culvert* will suffice, anything intermediate making little or no material difference.

* *Vide Molesworth's Pocket-Book*, p. 295.
† Byrne—*Highway Construction*, p. 382.

(B). *For Large Bridges* of some extent the main requirement is a topographical survey of the immediate locality of the bridge, to furnish a map showing a length of 300 feet on each side of the crossing, a profile of the approach track for a sufficient distance to ascertain at what height it is advisable to place the bridge; sounding contours to aid in locating abutments and piers, nature of river bed, and records of scour should be noted.

It is first necessary to find the flood discharge. To do so make three accurate cross sections of the river at the flood levels, the extremes being two miles apart. Maximum flood level must be found by local enquiry and, if possible, by flood marks; also by observing other existing openings on the same stream. Measure carefully the actual difference of water level between these extreme points; this will give the *surface* slope.

To obtain accurate results, scrape out a small channel in the bank, drive in an 8-inch peg till its top is exactly level with the water, and take readings *simultaneously*—which is not always easy to do. If this must be done in the dry season, when the river bed is dry, bore holes must be sunk and the difference of levels observed.

Ascertain from these three sections the mean value of the H.M.D., *i.e.*, area of waterway ÷ wetted perimeter, sometimes termed the mean radius (see *Molesworth's Pocket-Book*, p. 296):—

Let r = mean H.M.D. of the three sections.
s = the fall in feet per mile.
V = estimated natural velocity in feet per sec.

N.B.—This gives a rough approx. only of mean velocity.

A = estimated area of cross section.
v = safe bridge velocity (from Tables).
a = restricted area of bridge opening, less piers, *i.e.*, clear opening = net area of waterway.
Q = discharge in feet per second.
C = a constant depending upon s, r, and roughness of surface or channel.

We know the following relations:—

$$Q = AV = av.$$

Whence $$v = \frac{AV}{a},$$

and $$V = C\sqrt{rs}.$$

Hence the velocity and area of the restricted waterway can be found from the natural velocity and area. Refer also to *Water Supply, Cantonments*—Major Scott-Moncrieff, R.E., pp. 176 and 187, and *Hydraulics*, by Capt. H. D. Love, R.E., Madras.

It is usual to assume a certain value for v and make a depend

upon it. This value of v evidently depends on the nature of river bed and surroundings.

As an example :—

Assume the stream to be 100 feet width and the average depth 5 feet.

Assume that the bridge will consist of four arches 20 feet span.

Then $A = 100' \times 5 = 500$ square feet,
$a = 4 \times 20 \times 5 = 400$ square feet,
$V = \ldots\ldots\ldots\ldots 4$ feet per second,

and since $v = \frac{AV}{a} = \frac{500 \times 4}{400} \therefore v = 5\cdot$ feet per second, the increased velocity previous to passing through the bridge, owing to the restricted area and rise in the stream.

From *Molesworth's Pocket-Book*, p. 292, we find that the increased velocity (v_1) caused by any obstruction—in this case the piers $= \frac{1\cdot1\ AV}{a}$ and substituting, $v_1 = 1\cdot1 \times 5' = 5\cdot5'$ per second.

By reference to the Table of limiting velocities this would only be safe for a rocky bed. The levels of the arch springing should be at least 1 foot above the level of the "afflux"—or flood level (F.L.). If the banks require it, they may be made higher to suit.

It is as well to allow a good margin of safety, as hydraulic science has yet to evolve a formula for discharge of rivers universally applicable to rivers small and large, and of regular and irregular cross section.

Remembering that velocity increases approximately as the $\sqrt{\text{H.M.D.}}$ and that surface velocity is very different to mid-stream and mid-channel, and even bed velocity, more accurate results can only be attained by careful experiment with velocities at varying depths.

For Tables see *Roorkee Treatise*, Vol. II., para. 113, *Molesworth's Pocket-Book*, p. 292, *Navigable Rivers*, etc., *Trautwine*, p. 268, *et seq.*

Types of Flood Openings.—The following will be considered :—

(1). Flood causeways.
(2). Box culverts.
(3). Pipe culverts.
(4). Arched culverts.

(1). *Flood Causeways.*—In some cases, as in railway alignment, it is possible to supplement a series of culverts or a bridge by an arrangement in which the surplus water of an excessive flood may pass without injury over a low causeway or portion of line specially protected and laid. Such an arrangement is roughly indicated in

Figs. 89 and 90, where the surface is protected with loose stones and the water allowed to pass under the rails, and between specially designed C.I. sleepers, the railway at that part being a surface line.

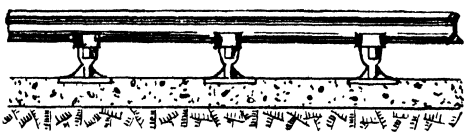


FIG. 89.

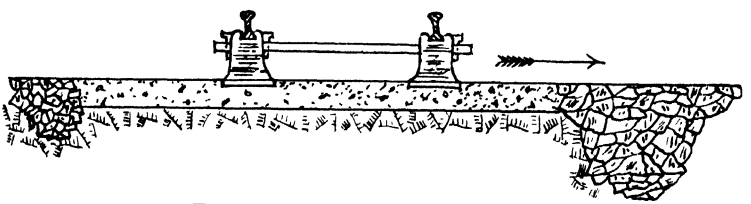


FIG. 90.—*Flood Causeway* (*Railway*).

(2). *Box Culverts* ("*Slab Drains*").—Small culverts of 2 or 3 feet square—box culverts—single or double, may be merely of roughly-squared stones laid dry, or in cement, and spanned by a stone slab, as in *Fig.* 91. One of these, 3 feet or 4 feet span, 5 feet high, will serve to discharge any ordinary well-defined ditch or stream. A common foundation is a stone pavement, under the entire culvert upon which the side walls rest. This is not good practice; for since the paving is liable to be washed out, it endangers the wall (see *Fig.* 91). It is best to give each wall an independent foundation with paving, or invert between the walls set in cement. If the current is rapid, the invert paving should be grouted (see *Fig.* 92).

The tendency of the pavement or invert to get undermined may be diminished by :—

(1). Sheet piling.
(2). Extending the pavement or invert at the entrance and exit.
(3). A deep apron wall at entry and outfall.

When the fall on discharge is considerable—as on a mountain road—a catchpool or water cushion should be provided above the entry to check velocity, dissipate energy, and break up the outlet descent with cascade steps. A large boulder in the pool will obviate damage (see *Fig.* 66). A drainage hole should be provided for catchpools or cantonments, lest they become mosquito-breeding grounds.

The thickness of the cover stones may theoretically be calculated

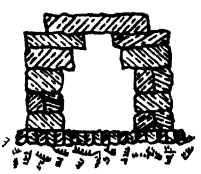


FIG. 91.



FIG. 92.

from the ordinary formulæ for beams, $M_{ff} = M_r = \frac{1}{8}Wl = \frac{3}{8}rbd^2$ (approximately for a concrete slab), but inasmuch as a large proportion of the superincumbent earth bank or road filling is practically self-supporting, the necessary thickness may be modified.

On the railroads in the U.S A. the covering stones—limestones or sandstones—average .—

Span,	2	feet.	Thickness of cover,	10	inches.
,,	3	,,	,,	12	,,
,,	4	,,	,,	15	,,

On the C.P.R. they are 14 inches, 15 inches, and 16 inches respectively.*

Box culverts are sometimes built double, with one wall common.

Fig. 93 shows the standard box culvert of the Intercolonial Railway, Canada, and is very substantially constructed.*

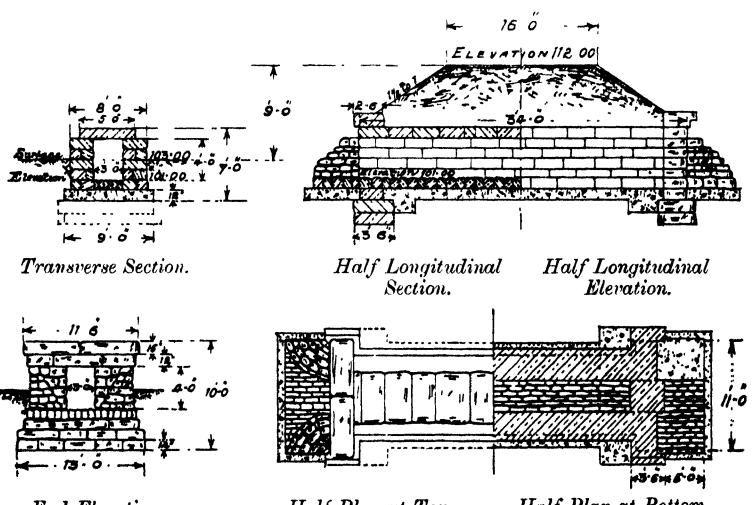


FIG. 93.—*Standard Box Culvert, Intercolonial Railway, Canada.*

* Baker, *Masonry Construction*, p. 400, *et seq.*

(3). *Pipe Culverts.*—Pipes, of vitrified stoneware, of the ordinary sewer-pipe type, up to 2 feet diameter, and of C.I. for larger diameters (up to 48 inches), have been extensively used. The average crushing strength of stoneware sewer pipe is 2,400 lbs. per square foot of horizontal section, and it is found by experience that such pipes will quite safely stand the weight of 24 feet of earth. The live load of a passing locomotive is considered equal to 5 feet of earth bank.

Fig. 94 shows a standard vitrified pipe culvert, Kansas Railway, and *Fig* 95 a standard iron pipe culvert which has given entire satisfaction.*

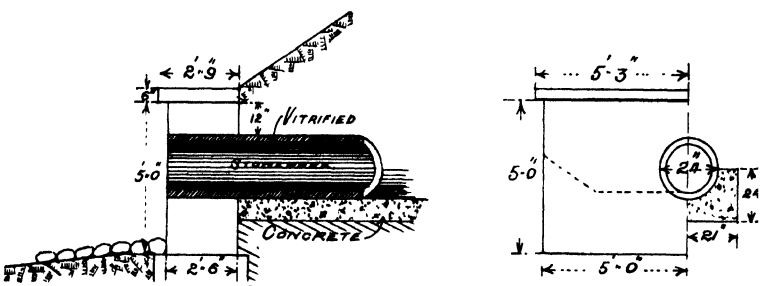


FIG 94.—*Stoneware Pipe Culvert.*

Reinforced or ferro-concrete cylinders and pipes will undoubtedly be more used in future. As a temporary culvert, or in a dry climate with a rainfall of less than 30 inches per annum, corrugated galvanized iron sheets, curved and riveted to cylindrical form, are useful; life, 10 to 21 years. By ramming concrete round them they become practically semi-permanent, and there is much less risk of leakage and a false passage. Timber may also be used, but will not last as long.

C.I. pipe culverts up to 12 feet in diameter have been laid on the Chicago, Burlington, and Quincy Railway. They are cast in quadrants, varying from 2, 4, 6 and 8 feet in length, and are bolted through outside flanges to any length.

Practical Points.—With pipe culverts the main points to see to are †:—

(1). That each end is protected with a suitable head wall (*Figs.* 96 and 97).

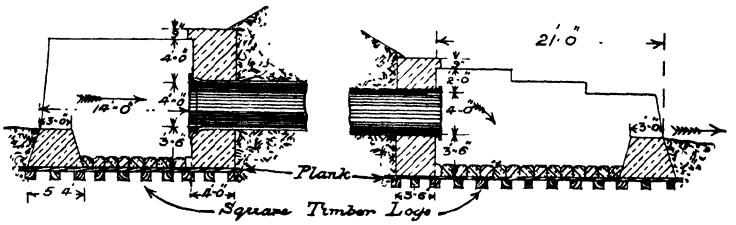
(2). That water will not form a false passage or channel along the outer skin of the pipe or opening.

* Baker, *Masonry Construction*, p. 400, *et seq.*

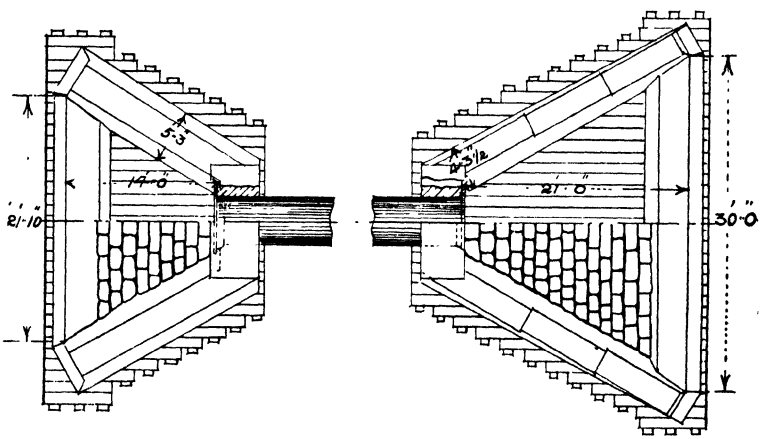
† From *Treatise on Masonry Construction*, by Ira O. Baker, Chap. 17, edition 1904.

(3). To lay to a camber, and so allow for settlement, which will be greatest at centre of the bank ; allow, say, 1 inch per 5 feet of vertical height of bank.

(4). That the joints are well filled and caulked with cement.



Section.



Plan.

FIG. 95.—*Iron Pipe Culvert.*

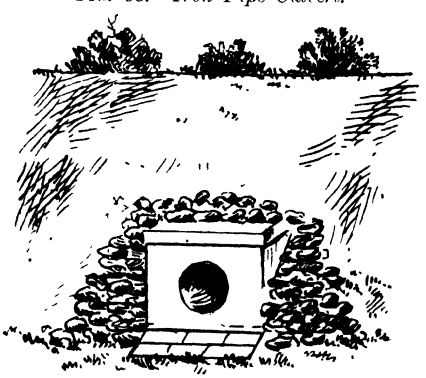


FIG. 96.—*Culvert Head-Wall (Permanent).*

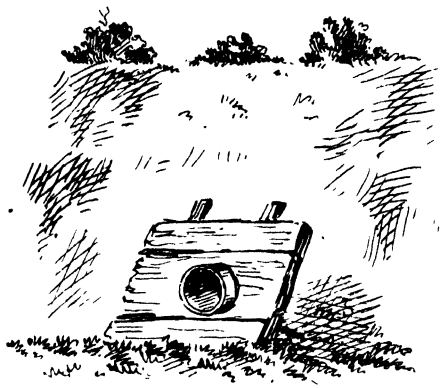


FIG. 97.—*Culvert Head-Piece (Temporary).*

(4). *Arch-Culverts.*—When the required span exceeds 5 feet, arch-culverts of stone, brick, or concrete, plain and reinforced, are usually employed. For spans above 15 feet it is better to design a bridge.

The provision of properly splayed wing walls facilitates flow on entry, reduces eddies, and promotes discharge. There are three common ways of disposing the wing walls (see *Figs.* 98 to 100). The most economical of masonry is *Fig.* 99, with wing walls at 30 degrees with the axis.

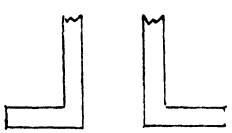


FIG. 98.

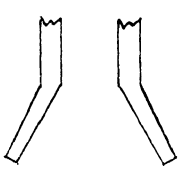


FIG. 99.

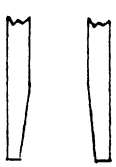


FIG. 100.

Fig. 98 causes eddies, and is liable to become choked.

Fig. 100 is deficient in splay, and does not protect the toe of the embankment.

Figs. 101 and 102 indicate how the wing walls are joined to the body.

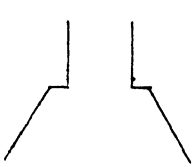


FIG. 101.

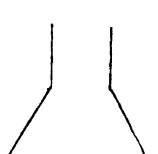


FIG. 103.

Figs. 103 and 104 are by far the best methods. The corners in *Fig.* 101 are very objectionable, and they are liable to get blocked by boulders, and are also expensive to form. Every angle adds to the cost of masonry. *Plates* VII. to IX. show very good standard types.*

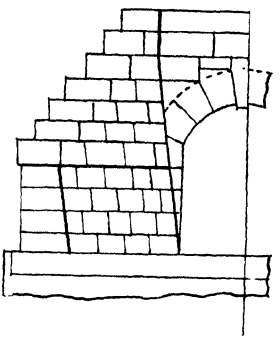


FIG. 102.

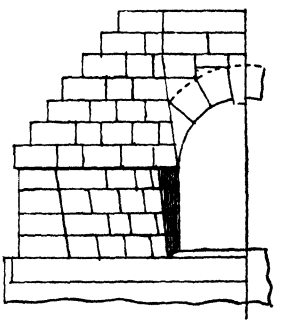


FIG. 104.

The arch may be semi-circular or segmental. The segmental arch has the greater advantage for the following reasons :—

For the same length of intrados the segmental gives a greater span and waterway, and consequently less risk of chokage by drift, etc., and because it will pass more water for the same depth. On the other hand, the segmental arch requires a thicker ring.

A rough rule for quickly determining the thickness of an arch ring in a masonry culvert is as follows :—

1 foot + (span ÷ 50) = thickness of arch ring in feet.
Rise $\frac{1}{4}$th span ; radius of intrados $\frac{5}{8}$th span.

Plates VII. and VIII. show comparative types, and the corresponding dimensions and contents are useful.*

The thickness of wing walls may be rather less than for retaining walls, brick or good rubble or cement mortar ; the thickness should be $\frac{1}{6}$th of the height throughout, or $\frac{1}{12}$th at top and $\frac{1}{3}$rd at base; top—18 inches minimum breadth for brick ; 13 inches for rubble.

Experience seems to indicate that the thrust on the abutments is more than met by the earth thrust. Consequently the natural deduction is that the abutment walls should be designed to resist the *earth*, not the arch thrust, in either circular or segmental culverts ; and inasmuch as the arch thrust is greater in the

* From *Treatise on Masonry Construction*, by Ira O. Baker, Chap. 17 edition 1904.

segmental, the abutments may be thinner than if the arch were semi-circular. Segmental arches are therefore cheaper and more efficient than semi-circular.

A standard arch culvert (designed by Mr. Ira O. Baker), *Plate* IX., embodies the preceding recommendations. The arch ring will support any bank. The best computation shows that if the earth is 10 feet thick over the crown, the maximum pressure is not more than 55 lbs. per square inch. A greater thickness of earth at the crown would doubtless increase the maximum pressure in the arch; but proportionally the pressure would increase much *less* rapidly than the height of the bank, inasmuch as ordinary earth has self-supporting strength. The arch is also stable under any position of the moving load, with either a heavy or light embankment.*

In districts subject to earthquake shocks, concrete culverts require reinforcement and to be built with "hinges" or pivots.

For information *re* "centres" *vide Manual of Masonry Structures.*

Increased Efficiency of Culverts.—The efficiency of a culvert may be materially augmented by :—

(*a*). A curved invert, so as to increase the H.M.D.
(*b*). Providing approaches or wing walls to guide the water, so that the discharge may enter without being retarded by eddies and projections.
(*c*). By sloping the bed of the invert, which should be paved.
(*d*). By damming up the water above the opening, so that it discharges under a head.

N.B.—A head of 4 feet will double the discharge under a head of 1 foot.

In general, it is better to provide a culvert too large than too small, lest, when the small culvert bursts and gets carried away, traffic will be suspended, and, moreover, a much larger culvert will be required in consequence.

In carrying a road over a culvert any sudden rise and fall over the crown should be avoided; the grades should rise regularly, to make even approaches and prevent damage to the arch ring.

Some very useful designs for culverts, from 1 foot and upwards, similar to the 3-foot slab drain (*Fig.* 105), and for small span bridges, 15 feet to 30 feet, with contents of wing walls, etc., and corresponding Tables for different rise and span, are given in *Specifications and Notes*, by Capt. E. L. Marryat, R.E.—the recognized P.W D. Handbook, Bombay (5th edition, 1902, G. of I. Press. Edited by F. L. Sprott) (see *Plates* VII. to IX. and XI.).

* From *Treatise on Masonry Construction*, by Ira O. Baker, Chap. 17, edition 1904.

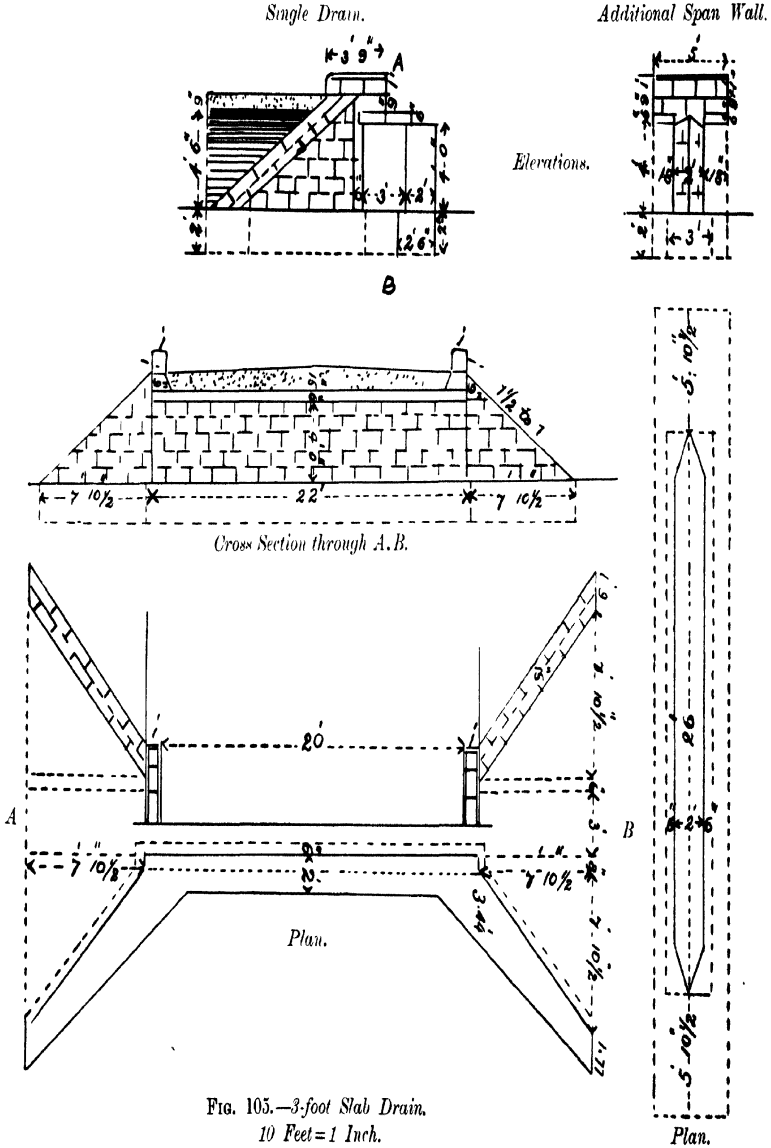


FIG. 105.—*3-foot Slab Drain.*
10 Feet = 1 Inch.

Light Bridges.—In opening out a new country by road building, the bridging of streams requires careful consideration.

The French engineers on the Congo—drawing on experience gained in their colonies—laid down the following rules, to which their bridges had to comply :—

1. A single span only to be used, avoiding intermediate piers, which, in time of freshets, might be wrecked by floating logs.
2. The general design to admit of the native timber being used to a considerable extent, and this with the minimum expense in squaring.
3. Provision to be made for renewing any portion of the timber, chiefly owing to the ravages of the white ant, without taking down the whole structure.
4. All metal parts to be capable of being taken adrift, so that the heaviest piece will weigh, including packing, not more than 66 lbs., this being the maximum weight which a native porter can handle.
5. The design of all bridges to be uniform, and the erection as simple as possible, thus reducing the employment of European labour to a minimum.

In order to comply with such conditions, bridges will often be made of the suspension type, wire rope being used wherever possible for the tension members, while timber will be employed for decking, longitudinal stiffeners, and frequently for the cross-girders. This form of bridge leaves the waterway unrestricted, and though much less rigid than required in permanent bridges, is preferable until the needs of the locality have been studied, as the new country is developed. They can be replaced by permanent structures in due course, to admit of railroads crossing the waterways.

The "single pier" or "half-loop" suspension bridge is a useful form for crossing a stream where there is considerable difference in level between the banks (*Figs.* 106 and 107); this form oscillates less than the usual type. In calculating strains, etc., the bridge can be treated as half a bridge of double span. Method of erection differs but little from that ordinarily adopted for suspension bridges; an adjustment of cable of 1 foot in 50 feet at the centre gives a satisfactory result.

On the Congo the form of suspension is somewhat unusual. The cables radiate in a vertical plane from the top of each of the side uprights. The two upper cables, one from each side of the span, articulate where they intersect opposite the centre of the bridge, and the remaining cables from the one side are coupled to the upper cable from the other side. At each of these articulations is a stirrup, from which is suspended one end of a cross-girder, which, in conjunction with others, carries the longitudinals of the roadway. Each of the cables is provided with a union coupling, by means of which its length can be adjusted. The main uprights are usually made of latticed ironwork,

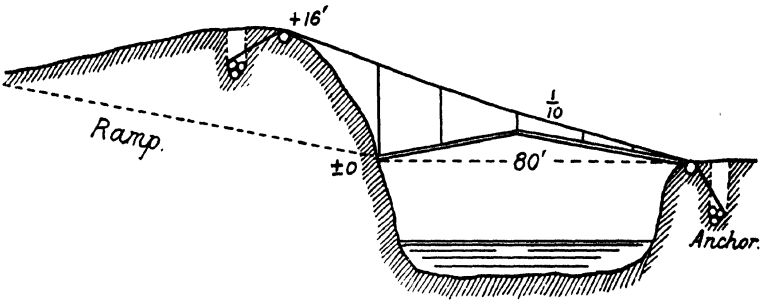


FIG. 106.

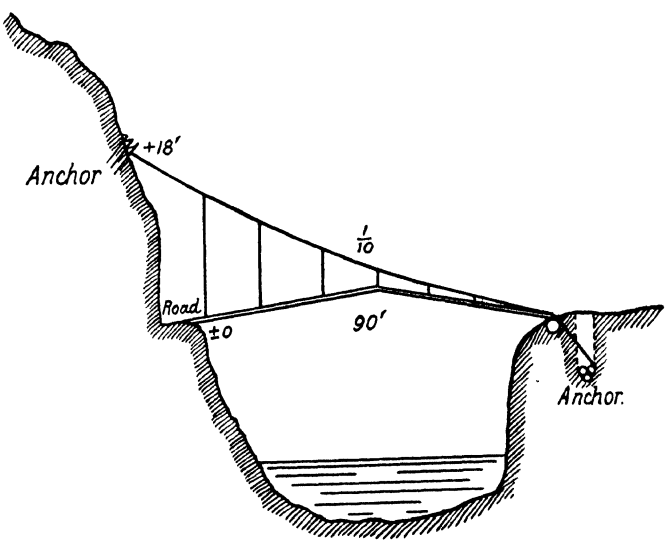


FIG. 107.

and are supported each by a gudgeon on a channel bar-shoe, which rests on the surface of the ground. The main anchorage is composed of T-bars driven into the ground, and braced together with channel-bars. The tops of the T-bars are at a depth of about 5 feet below the surface of the ground, and the soil excavated, in order to get these into position, is replaced by dry-rubble walling (see sketch, *Fig.* 108).

(Extracts from *Le Génie Civil*, Paris, Vol. XLV., pp. 279–82, quoted in Vol. CLX. of *Minutes of Proceedings of the Institution of Civil Engineers*, 1905, p. 418).

For information on light military bridges refer to *Military Engineering*, Vol. III., which contains Tables of loads of military carriages and pack animals, etc.

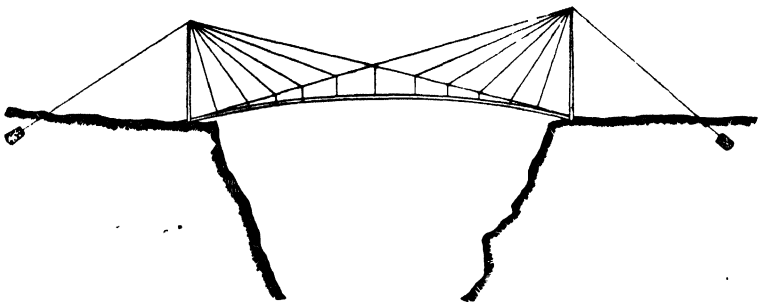


FIG. 108.

Scour.—To protect the foundations of bridges, piers, and abutments from scour and prevent the toe of a stone-pitched bank from being undermined often becomes a serious problem for the engineer. "Afflux" increases velocity through the waterway, and this in turn initiates scour.

The change in the bed of a river depends upon :—

(1). Soil of the bed and bank.
(2). Slope of bed, and velocity at bottom.
(3). Superficial obstructions.

Various Tables of scour for different materials are to be found in Pocket-Books, *Trautwine*, p. 279*f*; *Molesworth*, p. 292; *Roorkee Treatise*, Vol. II., para. 113, *et seq.*

A mean *surface* velocity of 5 or 6 feet per second (equivalent to $3\frac{1}{2}$ to $4\frac{1}{2}$ feet per second at the bottom) is dangerous to pier foundations not carried to considerable depth (40 feet), or built on a firm compact stratum.

If the bed be rock, an afflux of 3 feet even is not of much consequence; if of sand, the afflux cannot work up to more than a few inches, as scour will start, and the afflux must be reduced in a few hours' time. *Plate* XII. shows the result of scour in the years 1867 and 1871 upon the foundation piers in a waterway 61 miles from Calcutta, where eventually a hole 90 feet in depth was scoured out where flood openings had been made and added to, and 1,000 feet of embankment was carried away by successive floods. Two more flood openings, each 250 feet, were provided and floored with concrete 12 inches thick and 75 feet wide; drop or apron walls, protected with rubble pitching 30 feet downstream, were added on each side to prevent this paving being undermined; further damage to the bank occurred in 1885, so two more bridges of 400-foot and 200-foot openings were added, since which time these openings have withstood successive floods.

Scour develops thus :—First of all a pothole is formed by swirling

action. The chief aim of the engineer is to locate this, ascertain the cause, and then apply the remedy. A pothole occurs whenever an obstruction projects into the general current of a river, so as to shield a body of water under its lee (*Fig.* 109). This shielded body of water is set swirling by the main river current brushing past one side of it. This is the agency, however slow, which scoops out the pothole. It is not difficult, therefore, to locate or predict where a pothole will occur. Under ordinary circumstances, therefore, where an obstruction to the current is set up such as a pier or spur, a pothole *must* occur, and it is the engineer's duty to see that it does not

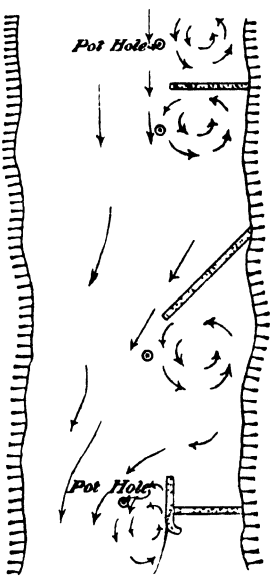


FIG. 109.

come dangerously near his bridge, pier foundation, abutment, or other structure, whose stability is threatened by the river's action.*

The action of scour is found to be at its worst when a river is rapidly rising and falling, and *not* at the greatest flood.

* *Fig.* 110 illustrates how a pothole was formed dangerously near a large pier by locating a guide bank spur in the wrong place, and how the inevitable pothole was caused to be removed away from the bridge by proper location of a new guide bank.

Refer *Technical Paper*, No. 114.—India.—Mr. F. J. E. Spring and others.

Again, scour may be greatest in an ice flood when narrow spans are apt to produce ice gorges, and thus force the current to undermine the foundations. In a small way the same thing results from floating logs and wreckage getting piled up across narrow openings. For this reason the piers of bridges are usually cigar-shaped; the "cutwaters" are sometimes fended with piles, or if the ends of the piers are rounded, a triangular boom of beams will serve the same purpose.

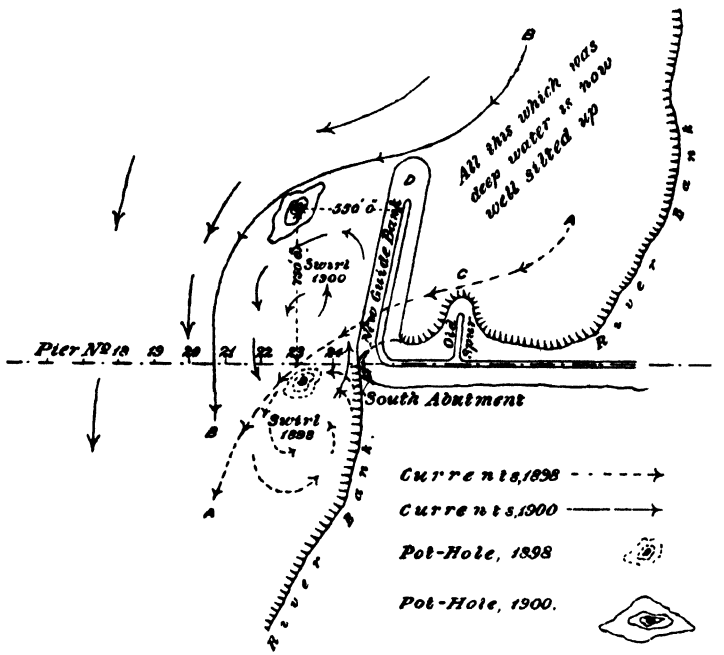


FIG. 110.

In the Argentine Republic floating "camalottes" moored to both banks are employed to break up the log drift. These camalottes are simply three logs secured together in the form of a triangle.

Practical Deductions.—It has been ascertained from practical experience that:—

(1). The mass of sand in river beds does *not* move for several feet below the bed, but only the merest surface film of the sand, which moves from moment to moment; as the velocity increases, more and more of this surface film is moved away, until appreciable scour results.

(2). An angular stone from 5 to 10 lbs. once it touches the bed will not move, even when surface and mean velocities are high.

(3). Blocks of stone weighing 80 to 100 lbs. are not moved at all, unless there be sand below them which has been undermined.

(4). Undermining will occur on the *down* stream side of a stone-pitched area.

(5). Scour in the Punjab Rivers, except under abnormal and whirlpool conditions, may be considered as extending not below 45 feet.

Remedies.—The practical remedies to minimize or prevent scour are :—

(1). Take the river direct through a bridge opening, employing "Bell Bunds" or guide banks, if necessary, to maintain an even flow (see *Plate* XIII.). To protect a long straight face of river bank from the eroding action of the current a quantity of loose (80 to 100 lbs.) stone, averaging 300 cubic feet per foot run of bank, is all that is necessary.

(2). Provide ample waterway and leave no *sudden* obstacles and no sharp bends.

(3). Use deep well foundations for piers and abutments, founded at least 30 or 40 feet below the greatest depth the river is likely to run.

(4). Provide a stone-pitched floor or paving between the piers just below normal scour level; or 12 inches of concrete or brick in cement (see *Plate* XII.).

(5). Surround the pier bases with an apron of stone 2 to 4 feet thick, of radius equal to the depth of the pier foundation.

(6). Provide drop walls on the *down* stream side.

(7). Where potholes occur it is only necessary to fill up with sand or other detritus, and cover the whole area with a thin layer of stone pitching or quarry and brick refuse.

(8). Secure a uniform depth of water in the waterway.

The following method has proved effectual :—

When it has been decided that the river shall nowhere be permitted to scour out its bed to more than a certain depth, leaving say 40 to 80 feet of pier foundation in the ground, each span can be treated in turn with pitched stone —taking the worst first, and leaving some unprotected ; these will probably be scoured out by the current in preference to those protected, and they can subsequently be pitched one after the other.

Eventually in process of years all the spans will have been treated with a

layer of light stone pitching, and there will be no tendency for abnormal scour to occur in any of them. Reference.—*Technical Paper*, No. 114, India, 1902. Mr. F. J. E. Spring.

As an illustration of practical protection, the following is quoted :—

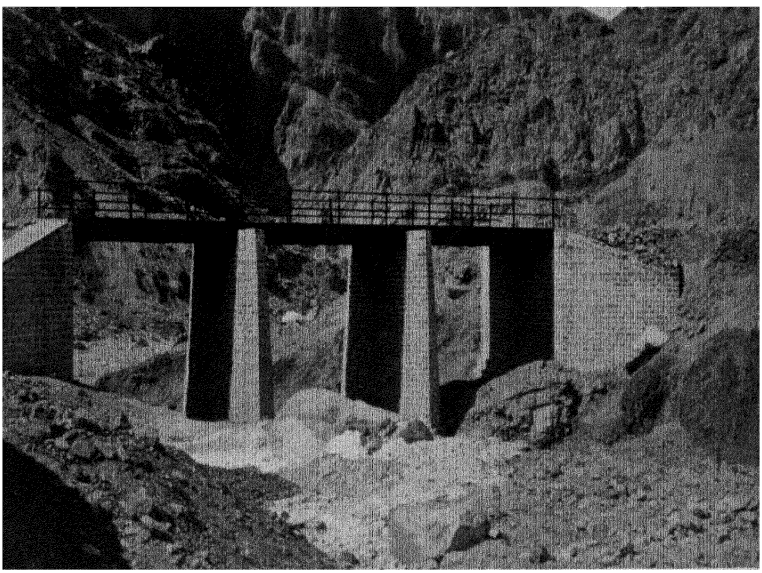
In forming a military suspension bridge over the Swat River during the Chitral Campaign, 1895, the following expedients were adopted to protect the pier foundations from scour :—It was not possible to take out the foundations of the masonry piers more than 2 feet below water level at the time of commencing work. The main channel was about 10 feet deep and running 7 miles an hour. The pier most exposed to scour was entirely surrounded by wooden crates or cribs, each 10 feet long by 5 feet by 5 feet; they were made of logs fastened together and to one another by telegraph wire. The crates and space enclosed by them were filled with boulders, thus forming an island 190 feet long and 44 feet broad round the pier. This protected the pier satisfactorily for a time; but when heavy floods (which rose to the top of the crates) came down, the river bed was scoured out right up to the crates, and the boulders began to drop out of them. To prevent this long rolls of wire netting filled with stones—the rolls, termed "sausages," being 3½ feet diameter—were placed along the front of the crates, and were held in place by pieces of wire cables carried back and fastened under the boulders forming the island. This had the desired effect, as the roll of stones could not be moved by the flood, and when scouring along it occurred, the roll dropped into the hole formed. In the case of other piers it was found sufficient to pitch well round the base, and between the piers, with stones On the left bank, which was very low and flooded at times, two long protective bunds were built to protect the bank forming the left approach to the bridge. The bunds were 6 feet wide at the top, with side slopes of 1 in 1, and were formed of alternative layers of boulders and brushwood, mixed with earth and grass roots. This formed a good protected bank.—*R.E. Professional Papers*, Vol. XXII. (1896).

Road Bridges.—Other things being equal, masonry arch road bridges of brick, stone, or reinforced concrete are superior and more lasting than steel girder spans. This is especially the case in mountainous tracts where transport is costly and stone plentiful and cheap. On the Indian frontier the difficulty and expense of bringing the members of steel bridges to site are considerable.

A very usual form is to build masonry piers, abutments and wing walls of masonry, and carry the roadway on steel joists and corrugated iron flooring. The piers, however, restrict the waterway.

The strongest form of arch is that in which the ratio of rise to span lies between $\frac{1}{4}$ or $\frac{1}{3}$ to 1, as then the arch realizes its best theoretical form under ordinary loading, namely, that of an inverted catenary. All masonry arches should be "bonded" and set in Portland cement or strong hydraulic lime mortar; arch rings are liable to separate and fail.

Trautwine, in his *Pocket-Book*, p. 694, lays down a very reliable rule for computing the requisite thickness of arches and abutments (*Plate* X.). As a practical deduction, small segmental arches are from 10 to 25 per cent. thicker than semi-circular.



Indian Frontier. -3-Span Bridge (15-ft. Openings). Piers and Abutments, Hammer-dressed Stone in Lime. Floor, Corrugated Iron Sheets (double), 4½-in. Metal. Beams, Rolled Steel (double). Handrails, 2-in. Galvanized Iron Piping and T Standards.

The formulæ are as follows :—

Road Bridge.—(Trautwine's rule) :—

Radius = $\{(\frac{1}{2}\text{ span})^2 + (\text{rise})^2\} \div$ twice the rise.

Depth of keystone in *feet* (d) for first-class cut stone arches

$$= \frac{\sqrt{\text{Rad.} + \frac{1}{2}\text{ span}}}{4} + 0{\cdot}2 \text{ feet.}$$

For second-class work increase by $\frac{1}{8}$th part; for brickwork $\frac{1}{3}$rd part to nearest dimension of bricks. The thickness T (pn) of the abutment in *feet* at springing level, when the height (ps) does not exceed 1½ times the base (ro), is given by the formula :—

$$\text{T} = \frac{\text{Rad. in feet}}{5} + \frac{\text{rise in feet}}{10} + 2 \text{ feet.}$$

Graphic construction of abutments, etc., is as follows (*vide Plate* X.) :—

Let pa = half the span, and ac the rise, dc depth of keystone; make $ab = \frac{1}{24}$th span and join bc; lay off T (pn) found above; from n draw no parallel to bc; make $ng = \frac{1}{2}\ ad$, and from g draw gx, touching the arch high up at x, or curved upwards to d; then gx will be the top of the masonry filling above the arch. From p draw pt at a slope $\frac{3}{2}$ from ps, cutting go at t; draw ts horizontal; if s is above ground level, make vr (thickness at base) $= st + \frac{1}{4}sr$, and draw vg' parallel to og. Then vg' is the back slope of the abutment, and $g'd$ the top of the masonry filling above the arch, g' being on a level with g; with arches of 60 feet span and over, or rise greater than $\frac{1}{5}$th span, the masonry should be carried up level with d.

Parallel spandril walls may be used to economize masonry.

Centres should not be struck until the masonry filling is complete, and the embankment carried up above the line of arch springing.

Abutments thus found will be safe without any dependence upon wing walls. Abutment piers, with slight batter on both faces, should be introduced in a series of arches.

Some useful types of masonry bridges, segmental and circular, for spans from 15 feet to 30 feet, are given in *Plate* XI.—taken from the Bombay P.W.D. Handbook. For useful Tables and information on wing walls, abutments, *vide Trautwine's Pocket-Book*, p. 702, *et seq.*

For further information on Road Bridges, Centres, and Arches, see *Manual of Masonry Structures* (S.M.E., Chatham).

Occasionally an engineer in charge of roads has to decide whether the bridges and culverts are strong enough to carry heavy wheeled traffic, such as loaded wagons drawn by steam traction engines or motor and trailer.

The author is indebted to H. Howard Humphreys, Esq., M. Inst. M.E., for *Plate* XIV., which gives in diagrammatic form wheel loads that are fairly representative of the usual type of road roller and traction engine with loaded wagons; also a curve diagram of equivalent rolling loads for road bridges, which may be used in calculating strength of girders.

Mr. Humphreys is of opinion that in girder bridges up to a span of about 35 feet (*i.e.*, of the average length of a heavy motor and trailer) the bending moments produced by a heavy motor car will be very little less than those produced by a traction engine and so much of its train as can be got upon the span of the bridge. At 60 feet span the ratio of bending moment will be roughly as ·75 to 1 in favour of the motor wagon; and at larger spans the case is still more favourable to the wagon.

It is fallacious to take the uniform floor loads per square foot usually given in text books, for the result with small spans will be

that both main and cross girders will be designed too weak, whilst in larger spans the cross girders will be too weak, and the main girder extravagant in material.

It might be supposed that the weight of wheels increased as the square of the diameter; actually the increase is rather less than the diameter. A rough rule to estimate the weight of wheels is:— Eleven times the diameter of a wheel in *inches* = the weight of the wheel itself in *lbs.* (Colonel Crompton).

For further information see *S.M.E. Manual of Bridge Design* (Steel Girders), and *Masonry Structures* (Arches), *Steel Concrete* (Winn), *Reinforced Concrete* (Buel and Hill).

APPENDIX A.

Grade Table.

Inclination (tangent), 1 in.	Angle with the Horizon.	Rise (feet) per Mile.
	° ′	
3	18 26	1760
4	14 2¼	1320
5	11 18½	1056
6	9 28	880
7	8 7½	754
8	7 7½	660
9	6 20	587
10	5 43	528
11	5 12	480
12	4 46	440
13	4 24	406
14	4 5¼	377
15	3 49	352
16	3 34½	330
17	3 22	311
18	3 11	293
19	3 1	298
20	2 51½	264
22	2 36	240
24	2 23	220
25	2 17½	211
27	2 7	195½
28	2 2	188½
30	1 54½	176
33	1 44¼	160
35	1 38½	151
37	1 33	143
40	1 26	132
43	1 22	123
45	1 16½	117
50	1 8	105½
55	1 2½	96
60	0 57¼	88
70	0 49	75½
80	0 43	66
90	0 38¼	59
100	0 34½	53
110	0 31¼	48
115	0 30	46
120	0 28⅓	44
125	0 28	42
150	0 23	39½
200	0 17¼	26½
400	0 8½	13

In America grades are designated by the rise per cent., *e.g.*, ¼ ft. per 100 = 1 in 400; a 4% grade = 1 in 25; 10%, 1 in 10, and so on.

APPENDIX B.

"Tarmac" is the name given by Mr. Purnell Hooley, of Nottingham, to the metal treated by his patent process, which was the initial step in providing a waterproof road surface with the aid of tar. The aggregate is picked ironstone slag, and it is impregnated whilst hot with a mixture of tar and other ingredients, which constitute the patent. Granite and syenite are too compact to absorb tar.

The cost of drying, and to ensure the complete coating of each stone with the mixture by frequent turnings over, is heavy, but as this is done at a central depôt by machinery, whereby the materials are delivered ready for laying and consolidation, the final cost hardly need exceed that of the ordinary macadam.

It furnishes an excellent road pavement, and has gone far towards the solution of the dustless roads problem, and reducing the renewal and maintenance bill *and rates*.

APPENDIX C.

Standing Orders and Specifications for Road Maintenance, Military Works Services, India, Plains and Hills.

CHAKRATA AND SAHARANPUR MILITARY ROAD.

SPECIFICATION No. I.—PLAINS.

Maintenance from Saharanpur to Kalsi, Miles 1 to 50.

1. Maintenance gangs shall invariably be kept on the road, their strength varying with the season of the year as detailed in the annual repair estimates.

2. Their duty will consist in—

(i.). Preserving the road between boundaries to its normal section and free from obstruction

(ii.). Repairing and making good all defects in metal, side widths, etc.

(iii.). Preserving and maintaining the road boundaries.

(iv.). Keeping all drains in an efficient state.

(v.). Preventing the traffic from damaging the road in any way other than by fair wear and tear.

(vi.). Maintaining the trees planted on the roadside.

(vii.). Keeping turfed banks in order and kerbstones in position.

(viii.). Removing weeds and plants from joints of masonry.

3. Repairs may be classed under—A, Earthwork; B, Metal; C, Jungle clearing.

4. **A.** *Earthwork.*—The best time for earthwork repairs is towards the end of, or immediately after, the close of the rains (from and after 1st September). At this time the sides of the road should be neatly made up to their normal slope of $\frac{1}{4}$, and the berms repaired where necessary, all additions of earth being thoroughly rammed; the slopes should also be made up where ruts and gullies have formed.

5. No earth for repairs is to be excavated outside the road boundary, ordinarily 81 feet side to side, without the written consent of the proprietor of the land.

6. Earth for repairs is only to be excavated between the boundary line and a line 11 feet from and parallel to the former, except where hillocks and rises occur. These may be cut down as required until the general level of the country and normal section of road is reached.

7. The earth for repairs is to be obtained from the side trenches, "borrow-pits," and as much attention must be paid to their symmetrical and neat appearance as to that of the road.

8. These "borrow-pits" may have a maximum width at top of 11 feet, and slopes of $1\frac{1}{2}$ to 1 where practicable; where not of 1 to 1 (the slope at boundary is never to be less than $1\frac{1}{2}$ to 1), they may have a maximum depth of 3 feet in open parts, and 2 feet near villages.

9. Where the soil is sandy or slope of ground considerable, these "pits" are not to be continuous, but made in lengths of 30 feet long, where a "bund," 5 feet broad at top and of the original level, is to be left. Where possible, the pits should be drained.

Where the soil is firm and slope moderate, the pits may be continuous and assist in draining the road.

10. Where cultivation is carried on, cart tracks are to be maintained at every furlong, or where necessary elsewhere, to afford access to the fields. These are to be 10 feet in width at top, side slopes $1\frac{1}{2}$ to 1, and to slope from the edge of the road to the road boundary. Where there is a drain at side of road, a culvert will be necessary.

11. Where the "borrow-pits" have already reached their maxima dimensions, and earth is still required, the berms may be reduced from level to $\frac{1}{4}$.

12. The turfing of banks and parapets must receive great attention during the rains, and must be put in hand immediately after the "monsoon" has broken.

13. On all embankments over 4 feet high parapets of earth, 3 feet wide at the base, 2 feet high, with 3-foot gaps in them at every 30 feet of length, should be kept up to their proper sections. Side slopes of embankments never to be less than $1\frac{1}{2}$ to 1.

N.B.—Where drainage can be arranged for without providing gaps, the latter should not be made. Where necessary, saucer-gutters must be carried down the bank slope to prevent the latter cutting.

14. Where the road is of the normal cross section, the section must be preserved; but steeper side slopes may be allowed and maintained where the soil will stand at a steeper angle.

15. The spoil banks must be kept up to prevent surface drainage reaching the road, and the side drains may be 2 to 3 feet wide, and from 6 inches to 12 inches deep, as per section.

16. In shallow cuttings the drainage of the inner side shall be led off by diagonal drains to a main drain excavated along the boundary line on the upper side of the road. The diagonal drains should be not more than 100 feet apart. The bottom of the main drain must be preserved not less than 1 foot below the formation level of the road.

Where the main drainage has to carry off a considerable quantity of water, it must be sufficiently deep to ensure that the drainage in the diagonal drains is not headed back.

17. At all seasons ruts in the berms should be kept filled up, and not allowed to acquire large dimensions. Watering and ramming will be necessary in the dry seasons.

18. **B.** *Repairs to Metal.*—The annual allowance of metal for petty repairs is 1,760 cubic feet per mile. The quantity in hand on 1st January must be carefully ascertained, and an estimate submitted for the quantity to complete each mile up to the above amount, making an allowance for the quantity likely to be used up during remainder of the official year.

19. The description of metal and its specification are the same as that for renewal, (see Specification No. III. for "Collection and Consolidation").

20. The positions for the "petty repair metal" stacks are shown by the existing compartments. Where these are non-existent, they should be formed, or the metal may be stacked in heaps of $10' \times 10' \times 1\frac{1}{2}'$, equivalent to 100 cubic feet at every 300 feet distance.

21. The "petty repair metal" will invariably be stacked on the west side of the road, and on the berm between the road bank and the trench, in neat heaps parallel to axis of road and near the trenches, so as not to prevent the berm being used for dry weather traffic.

22. At all seasons of the year small holes and depressions in the metal should be dealt with directly they occur.

23. A rectangular nick should be made enclosing the depression; the metal within this nick will then be picked up and removed to a depth of $4\frac{1}{2}$ inches at the shallowest part, and all dust removed and screened out. The bottom of hole will then be saturated with water, and a $\frac{1}{4}$-inch layer of powdered clay placed at bottom. Metal from the "repair metal" stacks shall then be filled in, the larger pieces packed below and the smaller above. On this must be spread $\frac{3}{4}$ inch of gravel or sandy clay, which is to be lightly picked in with a pickaxe until amalgamated with the metal. The patch may then be rammed dry with hand rammers till moderately firm. A $\frac{1}{2}$-inch layer of gravel or sandy clay is then to be spread evenly over the surface, watered, and when sufficiently dry (not wet enough to allow clogging of rammers) should be rammed again. Again, if found necessary, a $\frac{1}{4}$-inch layer of gravel may be added, watered and rammed, till well consolidated.

Finally, some fine stone screenings from the old metal, which was picked up and removed, should be sprinkled over the surface.

24. The above applies to stone metal, not to kankar. No gravel, earth, or clay is required with kankar. In all cases of repairing patches, the patch must on no account be made higher than the surrounding surface, as this leads to ruts being made all round it.

25. Extensive repairs to metalled surface should be put in hand immediately after the "monsoon" has broken, including the long ruts or depressions on each side of the crown, which are invariably formed in a road that is metalled for only 9 feet width. The centre portion, which will be high, may require picking as well as the ruts, and as much repair metal as is required to bring the surface to its normal section must be added.

Consolidation is to be carried out as above described (para. 23), but if the rainfall is copious, watering will not be required

26. During the rains the edges of the metal where loose and broken must be consolidated as above described, and care taken to preserve the correct line of the metal.

27. All petty repairs to metal require *daily* attention, and more or less ramming *until* perfectly consolidated.

28. When the stone-metalled road surface becomes rough owing to finer particles having been blown away, it is of great advantage to sprinkle "bajri" (disintegrated rock of the nature of coarse sand) over the surface during the hot season (March to July), as this prevents the metal working loose. Gravel, where obtainable, is the best material to employ for the purpose, but sandy loam may be used where bajri is not procurable.

29. Where repairs are in hand, or obstructions exist that are dangerous to traffic, a lighted lantern should be hung on a barrier at each end of the dangerous part.

30. **C.** *Clearing Jungle.*—Immediately after the close of the rains coarse grass and jungle are to be cut away from the banks, slopes, and berms, right up to the road boundaries; at the same time the road boundary nicks are to be renewed where necessary. During the rains, when the growth of rank grass interferes with the free discharge of surface drainage, it must be immediately removed.

31. All dead, unsound, and dangerous trees, which are likely to become a menace to traffic, must be felled, cut up, and removed. Growing trees must be lopped to admit sunshine and air—valuable accessories in drying the road surface.

NOTE.—For Notes on Arboriculture and Felling Trees see p. 154.

32. Burning grass, etc., within road limits must not be allowed, as it promotes the growth of rank grass.

CHAKRATA AND SAHARANPUR MILITARY ROAD.

SPECIFICATION No. II.—HILLS.

Maintenance from Kalsi to Chakrata, Miles 51 to 77.

1. Maintenance gangs shall be kept on the road, their strength varying with the season of the year as detailed in the annual repair estimates.

2. Their duties shall consist in—

(i.). Keeping the road surface side widths and slopes in repair, free from slips and obstructions.

(ii.). Keeping the metalled or unmetalled surface in repair, free from ruts and holes.

(iii.). Keeping all drains, both catch-water and side, in an efficient state.

(iv.). Keeping parapets in order and kerbstones in position.

(v.). Preventing the traffic from damaging the road in any way other than by fair wear and tear.

(vi.). Maintaining the boundaries.

(vii.). Maintaining the trees planted on roadsides.

(viii). Removing weeds and plants from joints of masonry.

3. The normal section of the road is as shown in *Figs.* 42 and 48; but in some places it is unavoidably narrower. The centre of the road shall be raised from 3 inches to 6 inches, according to the steepness of the gradient, viz. :—

1 in 20	6 inches
1 ,, 30	5 ,,
1 ,, 40	4 ,,
1 ,, 50	3 ,,

the greater the incline the greater the cross slope, to ensure rapid discharge of water diagonally.

4. Drainage on the inside will be carried off by the existing scuppers, and on the outside through the gaps in the parapets, which occur generally at every 20 feet; these gaps to be 2½ feet wide at bottom and 3 feet wide at top.

N. B.—Water should not be allowed to run along the outer edge of road for any distance, but be led through the gaps by means of small bunds.

5. The inner drains to vary in depth from 3 inches to 12 inches, side slopes according to nature of soil, viz. :—Vertical in rock; 2 in 1 in shale; 1 in 1 in clay.

6. No trees are to be cut without the written permission of the officers in charge.

7. The road boundaries are to be kept clearly defined, and high grass to be kept down within these limits.

8. No earth, gravel, or stones are to be taken from the side slopes; but projecting spurs may be cut back to afford material where the widening of the road is desirable, and the nature of soil not such as to threaten slips.

9. Stone required for building is on no account to be taken from above the road, as the men procuring it injure the slopes; but it may be obtained from approved places below the road.

10. During the rains the gangs should pay special attention to the road surface; a fresh coating of hard gravel or disintegrated rock of the consistency of very coarse sand should be spread over the entire road, the normal curvature being carefully maintained or corrected where necessary; and as it is important that this should be thoroughly consolidated by the close of the rains, the spreading of this gravel or bajri should be put in hand not later than the 1st June. Soft shale is often easily procurable, but is unsuitable as a coating, as it pulverizes readily.

11. Where any portion of road is metalled, extensive repairs to the metal are not to be carried on in the dry season.

12. During the rains frequent inspections of culverts, waterways, floors of bridges, and drains must be made, and in case of any tendency to scour, this must be at once checked with boulders or fascines.

13. During the rains all repairs to turfing slopes must be vigorously carried on; where the slopes are steep the turf must be pegged down.

14. At the close of the rains the gangs should be at once employed on repairing cuts, which have been caused by the rain, replacing earth covers and turf on the parapet walls, and cleaning out all drains and scuppers.

15. At all times ruts in the road surface should be filled with hard gravel directly they occur.

16. Extensive slips will be dealt with as special repairs, but the maintenance gangs should remove all minor slips and open out new catch-water drains above threatened places, so as to throw drainage into the regular water courses.

17. Parapets are to be kept neat and trim, and the turf on top and that of wheel-guards to be maintained in good condition.

18. Water supply on the road is to be kept in an efficient, pure, and uncontaminated state.

CHAKRATA AND SAHARANPUR MILITARY ROAD.

SPECIFICATION No. III.

Collection and Consolidation of Metal.

1. The metal is of two kinds, kankar and broken stone. It will be brought for each respective mile from the quarries specified in the sanctioned rate table.

2. The petty repair metal will be stacked in detached heaps on the west side of the road, and the renewal metal on the east side of the road. In both cases the metal will be parallel to the axis of the road on the spaces between the trenches (borrow-pits) and the road bank, but in such positions as not to prevent the berm being used for dry weather traffic.

3. For a 4½-inch renewal the stack will be 4½ feet mean width, and 9$\frac{9}{12}$ inches high, or 3 feet 4½ inches mean width and 13 inches high. The addition of $\frac{1}{12}$ will not be included in payments.

4. Openings in the stacks are necessary at every 100 feet for road drainage and other purposes, such as cart tracks to cultivated ground and entrances to properties; in such cases the width of the stack will be doubled for a corresponding length, or placed on the "bunds" between the trenches.

5. The collection is to commence at the beginning of one mile, and go on regularly to the end, and no payment is to be made till the metal is properly stacked and up to specification. Repair metal is not to be shot on the 27 feet of road surface or on the slopes, but must be stacked on the berm.

6. Collection of metal should commence as soon after the rains as possible, so that it may be ready for use on 1st of June of following year.

7. *Kankar Metalling. Collection.*—The kankar is to be hard and clean and fit in all respects for road metal. It is to be broken to 2½ inches gauge, and cleaned perfectly free from earth at *the quarries.*

8. *Kankar Consolidation.*—The kankar metal being at site, the consolidation must be carried out in the rains, and as during that season there may be many miles to consolidate, and heavy rain may at times impede the work, it should be an invariable rule to commence spreading kankar on *15th June*, so that it may be ready to take advantage of the first fall of rain. Where water is easily procurable, consolidation should be carried on at the same time, and such portions of road should be put in hand first of all.

9. The old metal is to be picked or scored in diagonal lines 12 inches apart. Then by additions and reductions of the old surface, where necessary, the bed for the new metal is to be formed to a curve with a template, as shown in *Fig.* 4, having a rise in the centre of 2⅜ inches. A cross slope of 1 in 24 gives a rise of 2¼ inches in the 9 feet of metal, but the apex or crown will be flattened, reducing the rise to 2⅛ inches.

10. When a sufficient length of surface has been prepared as above, two parallel mud walls about 10″ × 6″ will be made to retain the metal, a clear width of 9 feet being left between them.

11. Wooden templates for a 4½-inch coat will now be set up at convenient distances.

12. The kankar will be evenly spread between the mud walls, its surface flush with the templates, the large pieces being packed up below, and the small pieces above.

13. Ramming may at once go on, water being added if the rainfall is not sufficient to ensure consolidation.

14. As the work approaches completion, the surface must be corrected with the template shown in *Fig.* 4. High parts must be reduced by ramming, and low parts filled up with small nodules of kankar.

15. The consolidation must be continued until of sufficient hardness that a light cart would leave no impression of the wheel.

16. The berms and slopes must finally be made up to normal section, and the filling well rammed.

17. For several days after the kankar has been so consolidated, and the traffic is allowed to pass over it, a small party of men must be employed to

water the whole, and to ram such portions as show signs of disintegration, until such signs no longer appear.

18. No metal should be left on the road in heaps during the night time, but must be spread before the workpeople leave their work.

19. *Stone Metalling. Collection.*—The stone shall be hard boulders of granite quartz or limestone from those places noted in the sanctioned table of rates.

20. Sufficient stone for each mile shall be brought to site as boulders, and no boulder is to be accepted of less weight than 20 lbs. The sanctioned quantity of metal per mile is 17,820 cubic feet.

21. When all the boulders required for a mile are at site, breaking may commence; 1½-inch diameter rings will be provided, and all stones must be able to pass through them in every direction.

22. After breaking, the stone must be screened through ¾-inch iron wire screens; the broken stone and screenings will then be stacked as previously laid down (see paragraphs 2, 3, 4, 5).

The screenings should be stacked at regular intervals close to the stacks of metal, where they can be readily found afterwards.

The stacks of metal to be (for a 4½-inch layer) as laid down for kankar in paragraph 3.

23. *Stone Metal Consolidation.*—For preliminary operations, paragraphs 9, 10, 11, 12 for kankar consolidation are to be exactly adhered to, and should be put in hand on or immediately after the 1st of May of each year.

24. Spreading having been completed, a layer of fine earth or sandy clay, ¾ inch in thickness, equal to $100 \times 9 \times \frac{1}{12}$, or 56¼ cubic feet to each 100 running feet, is to be spread or jerked from baskets evenly over the whole surface. The earth is now to be mixed with the stone by light strokes of a pickaxe, until the two are fairly amalgamated.

Rolling may now begin, first along the sides and then along the centre, until comparatively firm.

As it is essential that the above process be carried out dry, it is most important to begin spreading by such time that the first rolling is over—by the 15th June. Spreading may therefore be commenced on 1st May.

When the rains have set in, a ½-inch layer of earth or sandy clay is to be added as before (in the early rains this can be obtained just below the surface), and the surface is to be watered if rainfall is insufficient. Rolling may then begin. The rolling must not, however, be commenced until the earth coating has again become sufficiently dry to prevent its adhering to the roller, which must not be allowed to get muddy, or else it will disturb the metal by its adhering to the roller. Dry dust should be frequently sprinkled over the roller to obviate this; this dust should be collected in April and May, and stored in some place where it will be protected from rain; small "chuppers" (shanties or lean-to sheds) with raised floor and well drained would answer.

Thirdly, ¼ inch or 18¾ cubic feet of earth per 100 running feet of road is to be evenly spread, well watered, and rolled until consolidated.

Finally, the stone screenings, previously alluded to in paragraph 22, to be evenly spread, watered, and rolled, until cart traffic on the metal leaves no impression, or until no grating sound is perceptible while the roller is passing over it.

25. The berms and slopes must be neatly brought back to normal section.

26. Metal must not be left in heaps on the road surface during the night, but must be spread before the workpeople leave work in the evening.

27. Not more than 400 lineal feet should be rolled at one time, and should rain fail, the surface must be kept wet after the rolling is completed for several days, and until the traffic and maintenance party have quite consolidated the surface.

28. With stone metal it is even more imperative than when kankar is used to keep a maintenance gang to look after finished portions, and it is only by perpetual care at first that the consolidation will be perfect. Where the nature of the earth renders it difficult to use a road roller successfully, hand rammers should be used.

Notes on Arboriculture, Felling Trees, etc.

1. In many cases two trees are originally planted side by side, as a precaution against one of them dying; two trees are subsequently found growing up together. When one or both of these trees is thriving and no longer requires watering, the inferior of the two is to be cut down at the ground level with a tenon saw.

N.B.—This should not be done until the growth of the better tree is assured.

2. In those cases where a seedling is coming up under another tree, both are to be left until the seedling, if an evergreen, attains a fair height, say 3 feet or 4 feet, when the deciduous tree is to be cut down.

3. At all times young shoots on the lower part of the trunk and suckers should be removed with pruning knives, a few of which will be kept in each subdivision, and the soil round roots should be loosened.

4. At all times the grass should be kept clear of the young trees, and on the 1st November of each year a circle of 12 feet diameter must be cleared round each tree, to guard against the risk of fire.

5. All young trees (say under 6 feet in height) must be protected by mud or bramble guards, to keep off goats and cattle; and to be efficient, these must be high enough to prevent cattle browsing *over* the guards. The guards must on no account interfere with the free growth of the tree, and where brick or mud guards are employed, ample through ventilation must be provided.

6. All trees which lean over should be propped, to grow straight.

7. Some trees are in hedges, and where the hedges are interfering with the free growth of the tree, the hedge should be trimmed to clear the tree, the owner's consent being obtained where necessary.

8. Felling of trees must be done with moderation. Large forest trees need to be cleared from bridle roads, but seldom for more than 25 feet on either side. Smaller trees are a useful safeguard against banks slipping.

9. The roots of surrounding vegetation absorb moisture from the road surface; some trees do this useful work better than others, notably the bamboo, the growth of which should be encouraged.

10. Where a 6-foot bridle track in jungle will be widened eventually to an 18-foot or 20-foot cart road, the belt of clearing should be made to the full subsequent width—about 45 feet. To defer this till the road is widened will enhance the cost and delay traffic.

11. The following is a rough journal of operations:—

January and February.—No water required; jungle to be kept clear for 12 feet.

March.—Uncover the plants which have been covered in for the winter (see further on), and begin watering young plants a little.

April, May, and half June.—Gradually increase the watering as the plants show they require it.

Half June, July, August, and September.—Cease watering. Fill in all blanks, where trees have died, with evergreen seed or saplings, *e.g.*, mango, tamarind, jaman, jack, bargat, pipal, bamboo, etc. (This must be done between the 15th July and 15th August). During these months keep the grass and jungle from choking the trees, and keep down the suckers on the trunks.

October.—Water slightly

November.—A little water may be required; this will depend on the season. In this month cover in the tender plants which would be injured by frost. The covers to be formed of grass, tied in a conical shape over three or four sticks, well stuck in the ground, and tied together at the top; the size of the cone will depend on that of the plant. Prune the branches of the trees slightly; also clear a circular space round each tree to guard against fire, the diameter of the circle to be 12 feet; and if high grass outside this approaches the branches, it must be removed.

The Renard Motor Road Train.

The Renard Sourcouf Road Train, invented by the late Colonel Renard, of the French Engineers, and improved by Messrs. Sourcouf et Cie, of Billancourt, motor car manufacturers, consists of a powerful motor vehicle, using petrol, steam, or oil, and a series of six-wheeled trucks and passenger carriages, the centre pair of wheels in each case being driven by the power developed by the motor, transmitted through the medium of a rotating longitudinal shaft, fitted with universal or "Cardan" joints, which enable the train to take curves easily. Each truck or carriage is, therefore, self-propelled, although all are coupled together by universal joints; consequently the strains are distributed over a larger number of wheels, and shocks to the vehicle and road surface are thereby reduced. One of the chief advantages of the Renard system is that a heavy traction engine is no longer required. The motor vehicle of the train is about 2 tons in weight. Little damage can be done to the roads by so light an engine, which is not under the necessity of gripping the road surface as a heavy traction engine does. Furthermore, the weight and power being distributed over the whole length of the train, it can ascend gradients with proportionate ease; instead of the engine having to drag the weight of the train, the latter, so to speak, pushes the former along, each unit having a propulsive force. Conversely, great power is secured, as when the motor is stopped it ceases simultaneously to work the other cars. Another important advantage is the steering arrangement, which compels each carriage to follow in the exact track of the one in front.

It is claimed that the train can double corners, or, having curled itself up in a garage or yard, can back out on its own track.

Among the uses to which the Renard train has already been put are the carrying of passengers between country towns not served by railways, and the collection of agricultural produce. A passenger service between Boulogne and Wimereux has proved a complete success.

Another has been established in Persia between Teheran and Resht, and six more services are being projected in the same country.

The first commercial train was supplied to a large firm of produce merchants in France, and has been running in all sorts of weather and on all conditions of roads for 18 months, with entirely satisfactory results. Indeed, the French Government is so convinced of the public utility of the invention that it has offered a subsidy to each *département* that establishes a goods and passenger service of Renard trains.

Their suitability for military purposes has also been recognized, one of the trains having been employed at the manœuvres of the Armée de l'Est.

In the War Office trials carried out in February, 1907, the consumption of fuel on the 35 miles run between London and Aldershot worked out at 0·351b. per gross ton mile on the down journey, and 0·345lb. on the return journey.

The gross weight of the train and its load of bags of sand and passengers was 19 tons, and the average speed from start to stop was 5·42 miles per hour on the down and 6·1 miles on the up journey.

The fuel was the ordinary petrol (sp. gr. 0·72), and cost 7d. per gallon.

During these tests the road surface between London and Egham was in good condition, and the weather was fine. On the Egham to Aldershot portion of the route the conditions were not so favourable, many long stretches of the road being under repair, and also soft and greasy from rain.

The train ran quite steadily at 10 miles per hour. The average speed over 10 consecutive miles was 8·7 miles per hour.

A hill over a mile long, on the main road near Aldershot, gradient varying from 1 in 38 to 1 in 10, the average gradient from top to bottom being 1 in 18·8, was negotiated at an average speed from bottom to top of 2·44 miles per hour.

APPENDIX E

BIDDER'S EARTHWORK TABLES.

ADAPTED FOR THE USE OF THE PUBLIC WORKS DEPARTMENT IN INDIA.

By F. L. O'Callaghan, C.E.

20·0	2000 **40000**																				
19·0	1950 **38033**	1900 **36100**																			
18·0	1900 **36133**	1850 **34233**	1800 **32400**																		
17·0	1850 **34300**	1800 **32433**	1750 **30633**	1700 **28900**																	
16·0	1800 **32533**	1750 **30700**	1700 **28933**	1650 **27233**	1600 **25600**																
15·0	1750 **30833**	1700 **29033**	1650 **27300**	1600 **25633**	1550 **24033**	1500 **22500**															
14·0	1700 **29200**	1650 **27433**	1600 **25733**	1550 **24100**	1500 **22533**	1450 **21033**	1400 **19600**														
13·0	1650 **27633**	1600 **25900**	1550 **24233**	1500 **22633**	1450 **21100**	1400 **19633**	1350 **18233**	1300 **16900**													
12·0	1600 **26133**	1550 **24433**	1500 **22800**	1450 **21233**	1400 **19733**	1350 **18300**	1300 **16933**	1250 **15633**	1200 **14400**												
11·0	1550 **24700**	1500 **23033**	1450 **21433**	1400 **19900**	1350 **18433**	1300 **17033**	1250 **15700**	1200 **14433**	1150 **13233**	1100 **12100**											
10·0	1500 **23333**	1450 **21700**	1400 **20133**	1350 **18633**	1300 **17200**	1250 **15833**	1200 **14533**	1150 **13300**	1100 **12133**	1050 **11033**	1000 **10000**										
9·0	1450 **22033**	1400 **20433**	1350 **18900**	1300 **17433**	1250 **16033**	1200 **14700**	1150 **13433**	1100 **12233**	1050 **11100**	1000 **10033**	950 **9033**	900 **8100**									
8·0	1400 **20800**	1350 **19233**	1300 **17733**	1250 **16300**	1200 **14933**	1150 **13633**	1100 **12400**	1050 **11233**	1000 **10133**	950 **9100**	900 **8133**	850 **7233**	800 **6400**								
7·0	1350 **19633**	1300 **18100**	1250 **16633**	1200 **15233**	1150 **13900**	1100 **12633**	1050 **11433**	1000 **10300**	950 **9238**	900 **8233**	850 **7300**	800 **6433**	750 **5633**	700 **4900**							
6·0	1300 **18533**	1250 **17033**	1200 **15600**	1150 **14233**	1100 **12933**	1050 **11700**	1000 **10533**	950 **9433**	900 **8400**	850 **7433**	800 **6533**	750 **5700**	700 **4933**	650 **4233**	600 **3600**						
5·0	1250 **17500**	1200 **16033**	1150 **14633**	1100 **13300**	1050 **12033**	1000 **10833**	950 **9700**	900 **8633**	850 **7633**	800 **6700**	750 **5833**	700 **5033**	650 **4300**	600 **3633**	550 **3033**	500 **2500**					
4·0	1200 **16533**	1150 **15100**	1100 **13733**	1050 **12433**	1000 **11200**	950 **10033**	900 **8933**	850 **7900**	800 **6933**	750 **6033**	700 **5200**	650 **4433**	600 **3733**	550 **3100**	500 **2533**	450 **2033**	400 **1600**				
3·0	1150 **15633**	1100 **14233**	1050 **12900**	1000 **11633**	950 **10433**	900 **9300**	850 **8233**	800 **7233**	750 **6300**	700 **5433**	650 **4633**	600 **3900**	550 **3233**	500 **2633**	450 **2100**	400 **1633**	350 **1233**	300 **900**			
2·0	1100 **14800**	1050 **13433**	1000 **12133**	950 **10900**	900 **9733**	850 **8633**	800 **7600**	750 **6633**	700 **5733**	650 **4900**	600 **4133**	550 **3433**	500 **2808**	450 **2233**	400 **1733**	350 **1300**	300 **933**	250 **633**	200 **400**		
1·0	1050 **14033**	1000 **12700**	950 **11433**	900 **10233**	850 **9100**	800 **8033**	750 **7033**	700 **6100**	650 **5233**	600 **4433**	550 **3700**	500 **3033**	450 **2433**	400 **1900**	350 **1433**	300 **1033**	250 **700**	200 **433**	150 **233**	100 **100**	
0	1000 **13333**	950 **12033**	900 **10800**	850 **9633**	800 **8533**	750 **7500**	700 **6533**	650 **5633**	600 **4800**	550 **4033**	500 **3333**	450 **2700**	400 **2133**	350 **1633**	300 **1200**	250 **833**	200 **533**	150 **300**	100 **133**	50 **33**	
	20·0	19·0	18·0	17·0	16·0	15·0	14·0	13·0	12·0	11·0	10·0	9·0	8·0	7·0	6·0	5·0	4·0	3·0	2·0	1·0	

N.B.—The full Table up to 60 may be had from the Roorkee College Book Depôt, Roorkee, India, price Rs.0 8 0, or mounted on cloth to fold up, Rs 1 8 0

Explanation.

The *ordinary* figures represent the content in *cubic feet* of any trapezoidal solid whose length is 100 feet, width 1 foot, and whose depths at the ends are indicated by the numbers of the intersecting columns; and are intended to be applied to the central part of any cutting, exclusive of the slopes. The *black* figures show the contents of 1 to 1 slopes, whose heights are shown as before.

To find the contents of any cutting or embankment by the Tables:

First find the greatest height in the bottom line and the less height in the left-hand vertical column, and refer to the intersection of the vertical and horizontal columns.

Multiply the *ordinary* figures there found by the width of the base of the cutting, and the *black* figures by the ratio of the slopes, and the sum of the products will be the contents required.

Example.

To find the contents of a cutting whose longitudinal section is represented by *Fig.* 1, and cross-section by *Fig* 2.

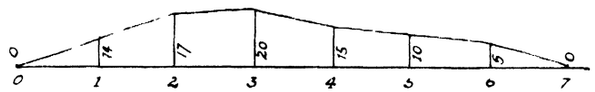


Fig 1.

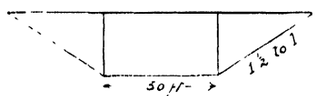


Fig 2

At the intersection of the columns 14 and 0 are 700 and 6533, which insert in the columns *a* and *b* of the following scheme; at the intersection of the columns 14 and 17 we have 1550 and 24100, which insert as before, and so on to the end. Then multiply the sum of the numbers in *a* by 30, the width of base and the sum of the quantities in *b* by 1½ the ratio of the slopes, and the sum of those products will be the required contents.

Heights	*a*	*b*
0 | 14	700	6533
14 | 17	1550	24100
17 | 20	1850	34300
20 | 15	1750	30833
15 | 10	1250	15833
10 | 5	750	5833
5 | 0	250	833
Totals	8100	118265

8100 × 30 = 243000 = content of centre.
118265 × 1½ = 177397 = ,, slopes.

420397 = total content.

The slope table is used for finding the *areas* of slopes, the figures in the column R being the ratio of the slope to 1.

To find the area of the slopes of a cutting or embankment, multiply the total of column *a* by the tabular number (N) corresponding to the slope ratio, and *double the product* will be the area of both slopes.

Example.

8100 × 1·8 × 2 = 29160 required area in square feet.

Slope Table

R	N
¼	1·03
½	1·10
¾	1·25
1	1·41
1½	1·80
2	2·23
2½	2·70
3	3·16
3½	3·64
4	4·12
4½	4·61
5	5·09
6	6·08

APPENDIX F.

EXTRACTS FROM A PAPER BY MR. GEORGE CHAMIER, M. INST. C.E., ON CAPACITIES FOR CULVERTS AND FLOOD OPENINGS.—VOL. 134, MINS. OF PROC. INST. OF C.E., 1898, P. 313, ETC.

Calculations are based upon :—

(1). Catchment-area.
(2). Rainfall.
(3). Amount of surface-drainage.
(4). Diminution in proportionate flood discharge due to area.

Catchment-Area.—For *small* catchment-areas the extent of the drainage basin should be fairly accurately known. In the case of *large* watersheds, however, comprising several hundreds of square miles, the element of area is important. The *form* and *greatest length* of the catchment-area are of almost as great consequence as its *extent*, and so also are the *outlines of the principal valleys* and the distances traversed by the main water courses. The latter information is essential, for upon it will depend the *time* required for the flood waters to reach the outlet from the farthest extremities of the catchment. It is upon this time that the *rate of precipitation*, to be adopted in the calculation, will mainly depend. It is also important to note the general declivities of the ground and the average fall of the valleys towards the outlet as affecting the *flood velocities* of the streams. It must be assumed that the rain is general, and falls over the whole extent of the drainage-area simultaneously, and is of sufficient duration to allow the flood waters from all parts of the drainage-area to reach the outlet at the same time.

Rainfall.—The *duration of the rainfall* is the main consideration, but this period is intimately connected with the extent of the drainage-area and the velocity of the flow, which depends mainly on the inclination of the country. The average *rate of the precipitation* is found everywhere to vary inversely as its duration. In temperate zones as much as one-fourth of the mean yearly rainfall has been known to occur in one day, and about one-fourth of the maximum daily fall has been registered in one hour. The general rule is to take the greatest rainfall to be anticipated, from previous records, for such a time as is required for the flood water to reach the outlet from the farthest extremities of the catchment-area. This is the only safe basis to proceed upon.

In New South Wales the maximum rainfall for one hour approximates to one-fourth of the greatest daily fall. In a period of four hours the maximum is about double that for one hour. This proportion would appear to hold fairly well in many other places, and where it is at fault it will be found to err on the safe side.

The corresponding figures would be :—

Duration in hours	1	4	12	24
Rainfall in inches	1	2	3	4

Heaviest rain is not usually of a continuous character, but falls in intermittent showers. This fact, however, does not affect the matter under consideration, For the purpose of calculating the greatest flood discharge all that is needed is approximate knowledge of the maximum rainfall that may occur during a period corresponding with the size of the catchment-area.

If the area is so large that only the greatest daily fall need be taken into account, it will not materially affect the result whether the rain falls at the same rate for 24 hours, or whether it falls in heavy and intermittent showers, over the same period.

As regards fixing of the duration corresponding with different areas. Here it is required to estimate the time needed for the flood-water to traverse the whole length of the catchment-area, which is almost impossible to determine exactly. But the velocities of streams can always be approximately ascertained from the dimensions of the channel, the volume of flow and fall of the land. These velocities, under average conditions, may be taken to range between two miles and four miles per hour. The case of a mountain torrent or of a rapid river would be different. The time that rain-water takes to flow off the surface of the ground into rills or feeders can only be guessed, and must depend mainly on the nature and inclination of the ground. Over grassy downs, with moderate slopes, the rate of flow for surface drainage may be estimated at half a mile per hour, while for steep declivities the rate will be about twice as great. When the water is collected into well-defined channels, the velocity admits of being approximately calculated, and the estimate can always be rendered safe by assuming the least time the water could be expected to take in passing over a known distance, under given conditions. The less time allowed the greater the margin of safety.

Surface-Discharge.—Only a certain portion of the rain which falls on the surface need be taken into account in calculating the flood discharge at any outlet. There is loss of water from :—(1) *Absorption*, (2) *evaporation*, (3) *percolation* into subterranean channels. By "co-efficient of surface-discharge" is to be understood that portion of the rainfall which immediately flows off the surface and finds its way into running streams. It would be extremely difficult to estimate this amount with confidence, if all the varying conditions had to be taken into account ; but it is only the *maximum discharge* under conditions most conducive to surface-drainage which has to be dealt with.

In countries where the ground is often frozen, and thereby rendered almost impervious, it is usual to assume that two-thirds of the total precipitation will flow off the land in times of flood, as a maximum. But in warmer climates it is necessary to take into consideration the absorbent nature of the soil, the slope of the ground, and the physical features of the country. In all cases, however, the utmost previous saturation, which the conditions of the climate and rainfall will permit, should be allowed. As a general rule, the co-efficient of surface-discharge may be taken to be between one-third and two-thirds of the total rainfall, in times of flood.

The co-efficient of surface-drainage may be taken approximately for :—

Flat country, sandy soil, or cultivated land ...	0·25 to 0·35 per cent.
Meadows and gentle declivities, absorbent ground	0·35 to 0·45 ,,
Wooded hill-slopes and compact or stony ground	0·45 to 0·55 ,,
Mountains and rocky country or non-absorbent surfaces	0·55 to 0·65 ,,
Unfissured mountains, very steep ground, or paved streets	0·8 and over ,,

A co-efficient of 0·50 may be assumed as an average, with 0·65 as a maximum for ordinary cases.

Diminution in Proportionate Flood-Discharge due to Area.—It has been proved by experience that flood-volumes are inversely proportional to the extent of the catchment-areas. This rule has been embodied in all formulæ for calculating flood-discharges. The *ratio of decrease according to area*, however, has not been determined with certainty. Most formulæ are empirical and assume uniform conditions of rainfall and surface-drainage. Rainfall varies very greatly in different countries, and even in different parts of the same country, and the physical conditions are so diverse that such

formulæ do not admit of general application. The diminution in the flood-volume due to area must not be confounded with the diminution in rate of rainfall on account of its duration, which is also related to the extent of the watershed. Although both these causes conspire to decrease the flood-discharge at the outlet, they are quite different, and must be taken separately. If a uniform rainfall, of sufficient duration to give the maximum results in both cases, occurs on two catchments of one square mile and 1,000 square miles respectively, the flood-discharge from the large area will not nearly be 1,000 times that of the small one. The volume will be greatly reduced by evaporation, absorption, and generally by percolation through the surface, but chiefly by the obstructions which impede the flow, and thus diminish the rate of discharge if they do not reduce the quantity.

Mr. Chamier's experience and observations indicate that for average cases $\frac{M^{\frac{3}{4}}}{M}$ may be adopted as the ratio of decrease due to area, where M denotes the area of the catchment in square *miles*. It has given remarkably accurate results, but probably other powers of M may be found necessary under different conditions; the question admits of determination only by observation in many places.

Method of Calculation.—It may be assumed that 1 inch of rainfall per hour, on one acre of surface, gives a discharge at the outlet of 1 cubic foot per second, supposing all the water to flow off. The number of acres, A, therefore, multiplied by the average rate of rainfall per hour in inches and by the co-efficient of surface-discharge, will give the maximum flood-discharge to be provided for. But where the watershed exceeds one square mile, the factor for diminution according to area, $\frac{M^{\frac{3}{4}}}{M}$, should be included in the expression. Thus—

$$Q = A \times C \times R \times \frac{M^{\frac{3}{4}}}{M};$$

substituting for A its value in square miles.....$\left(\frac{A}{640} = M\right)$.

$$Q = 640 \times C \times R \times M^{\frac{3}{4}},$$

when Q denotes the maximum discharge at the outlet in cubic feet per second;
R = the average rate of greatest rainfall anticipated in inches per hour, for such duration as will allow of the flood-water flowing to the outlet from the farthest extremity of the catchment area;
and C is the co-efficient of surface discharge, giving the proportion of rainfall that may be expected to flow off the surface.

The leading characteristic of this formulæ is that it takes special account of the duration of the rainfall.

As an example :—Rainfall assumed at 12 inches for 24 hours, with a maximum of 3 inches for one hour; C taken at its greatest value ·66; A, 75 square miles, with 14 miles as the longest distance for the flood-water to traverse; a rapidly discharging basin, with compact and steep ground; and the inclination of valleys such as to give the main stream an average velocity of about 3½ miles per hour. It follows that the duration of the rainfall would have to be taken for a period of not less than four hours, and, as the greatest downpour in that time could not be expected to exceed 6 inches, the average rate would be 1½ inches per hour (R).

Then $$Q = 640 \times \cdot 66 \times 1\tfrac{1}{2} \times \sqrt[4]{75^3} = 16{,}384.$$

If the maximum be taken at 12 inches of rain for one day, then the maximum for one hour should certainly not be less than 2 inches. In

Sydney, for instance, the records for the past 25 years show that the heaviest rain for one day has been nearly 12 inches, that for four hours nearly 6 inches, and for one hour about $2\frac{1}{4}$ inches.

Mr. Chamier was afforded an excellent opportunity of testing the accuracy of the formulæ by a number of conclusive observations, in January, 1897, while engaged in an investigation as to the sufficiency of the waterways on the Cootamundra-Gundagai Railway, for the Government of New South Wales. This line is situated on the south-eastern portion of the colony. It is about 30 miles in length, running over undulating land and skirting a steep range of wooded hills to the west. Numerous small creeks, and also several larger water courses issuing from the high ground, cross the line; the catchment-areas vary from 20 acres to more than 400 square miles. The watersheds had been surveyed, and information had been collected as to the positions and lengths of the main streams and the average slopes of the ground. The mean annual rainfall for the district was 26 inches, and the greatest recorded fall for one day was somewhat more than 5 inches.

A few average cases are given by way of illustration, ranging from very small catchments to the largest.

Case 1.—Area 586 acres. A flat gully with steep hills at the sides; clear grassy land; C 0·40. This being a small basin, it was required to take the heaviest downpour for one hour, which on this occasion was about $\frac{3}{4}$ inch.

Maximum discharge by formulæ = 176 cubic feet per second.

Maximum discharge by measurement = 122 cubic feet per second.

Case 2.—Area $2\frac{1}{2}$ square miles. Creek bed very tortuous, valley about two miles to the foot of steep hills; greatest distance for the water to travel about four miles, which would take fully two hours; C taken at 0·50; the greatest rainfall for two hours' duration could not be ascertained with certainty, but it must have been nearly $\frac{1}{2}$ inch per hour (R). Then by the formulæ—

$$Q = 640 \times 0{\cdot}50 \times \tfrac{1}{2} \times \sqrt[4]{2\,5^3} = 319 \text{ cubic feet per second.}$$

Actual discharge by measurement = 210 feet per second.

Case 3.—Area 49 square miles. The principal valley about 13 miles long, with a rise of 20 feet to the mile; the water had to travel over 20 miles, which was estimated to require seven or eight hours. For the value of R 3 inches fell in seven hours, so that the average rate was $\frac{3}{7}$ inch per hour.

$$Q = 640 \times 0{\cdot}40 \times \tfrac{3}{7} \times \sqrt[4]{49^3} = 2{,}035 \text{ cubic feet per second.}$$

Actual discharge by measurement = 1,820 feet per second.

Case 4.—Area 418 miles; the main water course extended back 26 miles, with many miles of branches; a flat valley, with an inclination of 142 feet in 15 miles. It was assumed that flood-water would take about one day to traverse the whole length of the basin. Nearly 4 inches of rain fell in one day, so that the average rate of precipitation was $\frac{1}{6}$ inch per hour. The land in the valley is partly arable, but the hills are steep and wooded; C taken at 0·45. Then—

$$Q = 640 \times 0{\cdot}45 \times \tfrac{1}{6} \times \sqrt[4]{418^3} = 4{,}435 \text{ cubic feet per second.}$$

Actual discharge by measurement = 4,681 cubic feet per second.

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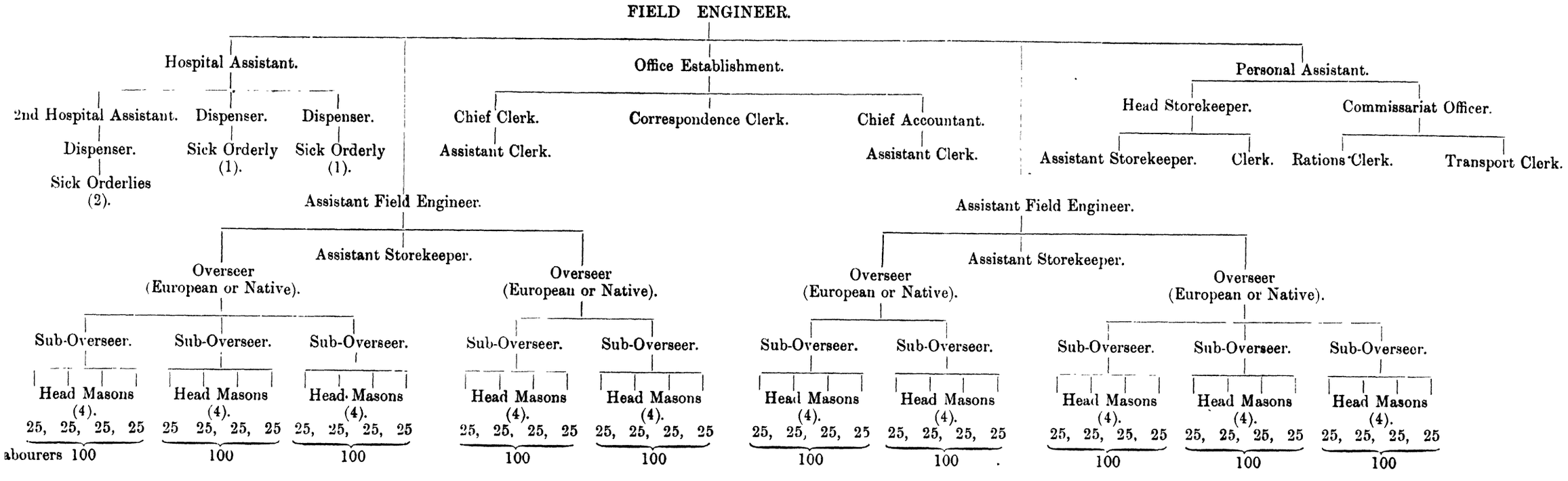
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ROAD STAFF AND LABOUR ORGANIZATION.



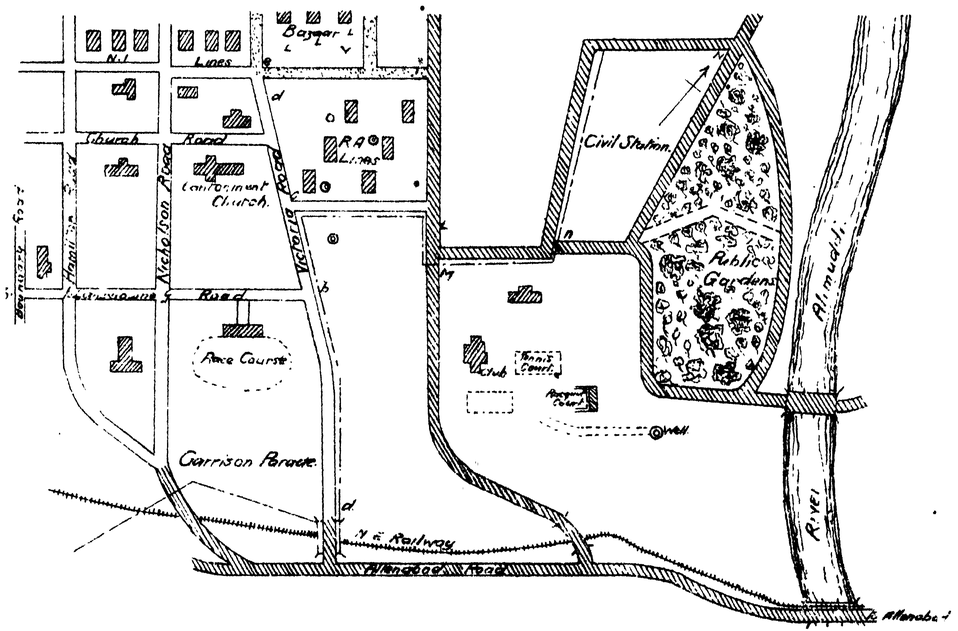
Field and Assistant Engineers with Personal Assistant	4
Office Establishment	5
Overseers (European, 2; Native, 2)	4
Sub-Overseers	10
Hospital Assistants (2), Dispensers (3), Sick Orderlies (4)	9
Storekeepers and Assistant Staff (4), Clerk (1)	5
Commissariat Staff (1), Rations and Transport Clerks (2)	3
Head Masons	40
Masons, Miners, Labourers	1000
	1080

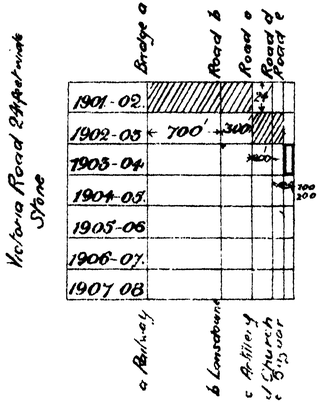
NOTE.—Each *section* may be designated by a letter, A, B, C, etc., and comprise so many gangs.

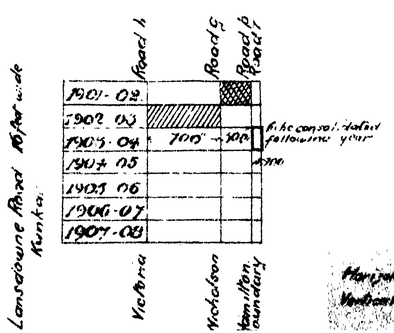
Two or more sections may be grouped as convenient into *divisions*, designated 1st, 2nd, 3rd, etc.

The length of road allotted to a division or section can best be determined by the character of the locality and merits of each case.

ROAD PLAN OF RAIPUR CANTONMENT.







Horizontal Scale 1 inch = 1200 feet
Vertical Scale 1 inch = 1 Foot

Imperial-Military Fund Road
Provincial- do do
Cantonment- do do
Cantonment Boundary.

1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Name	Section	Length in Feet	Width in Feet	Metal		Cost Renewal		Cost Maintenance Annual.		Life	Next due	Remarks
					C Feet	Consolidated from C Feet	Collection	Consolidation	Collection	Consolidation	Years	Season	
							Rs.	Rs.	Rs.	Rs.			
ae	Victoria Road	a b	700	24	8400	840	180	30	8	6	6	1907-08	Imperial Military Cantonment Fund Provincial
	"	b c	300	24	4000	400	80	30	8	3	6	1907-08	
		c a	200	24							1	1908-10	
		d e	100	24							1	1910-11	
	Totals.		13000	24									
pz.	Lansdowne Road.	h g	700	16	6000	600	100	20	25	5	5	1907-08	Total Length of Road
	"	g p	300	16	2400	240	50	10	14	3	5	1906-07	
		p z	100	16	800	80	10	2	3	2	5	1908-09	
	Totals.												

Metal collected one year.
Same Metal consolidated following year.
Metal collected and consolidated same year.

NOWSHERA—SHERGARH ROAD.

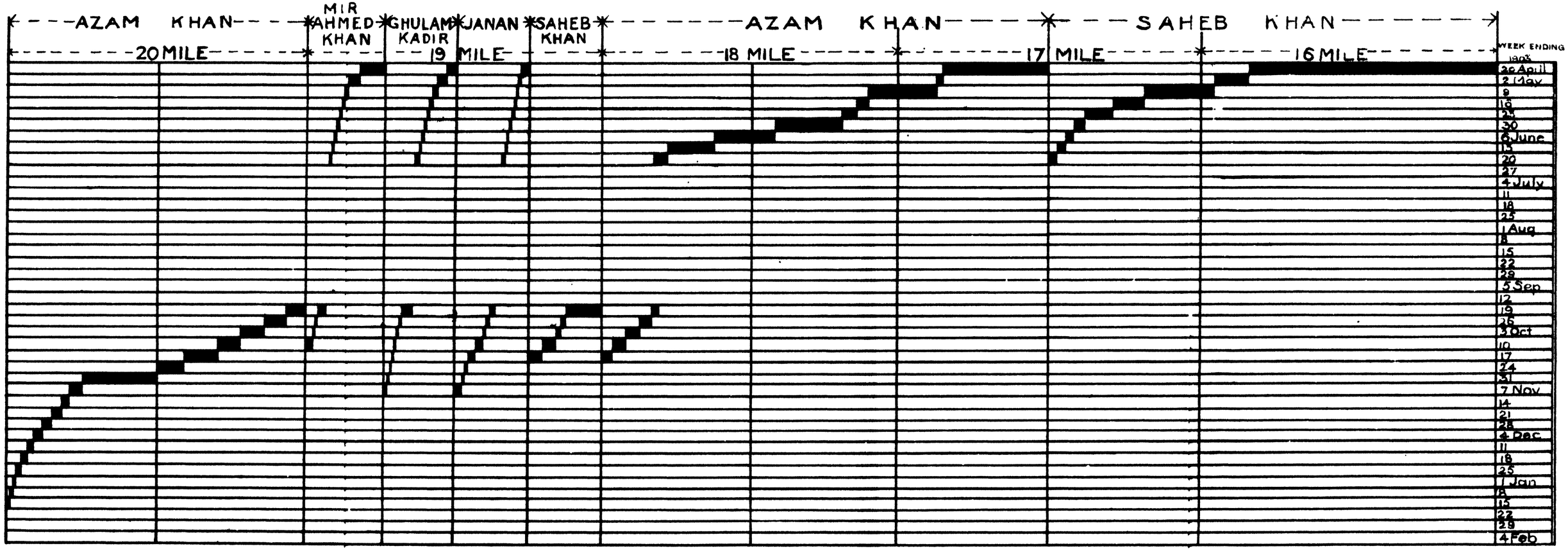
MAINTENANCE CHART.

No. of Miles from Nowshera.

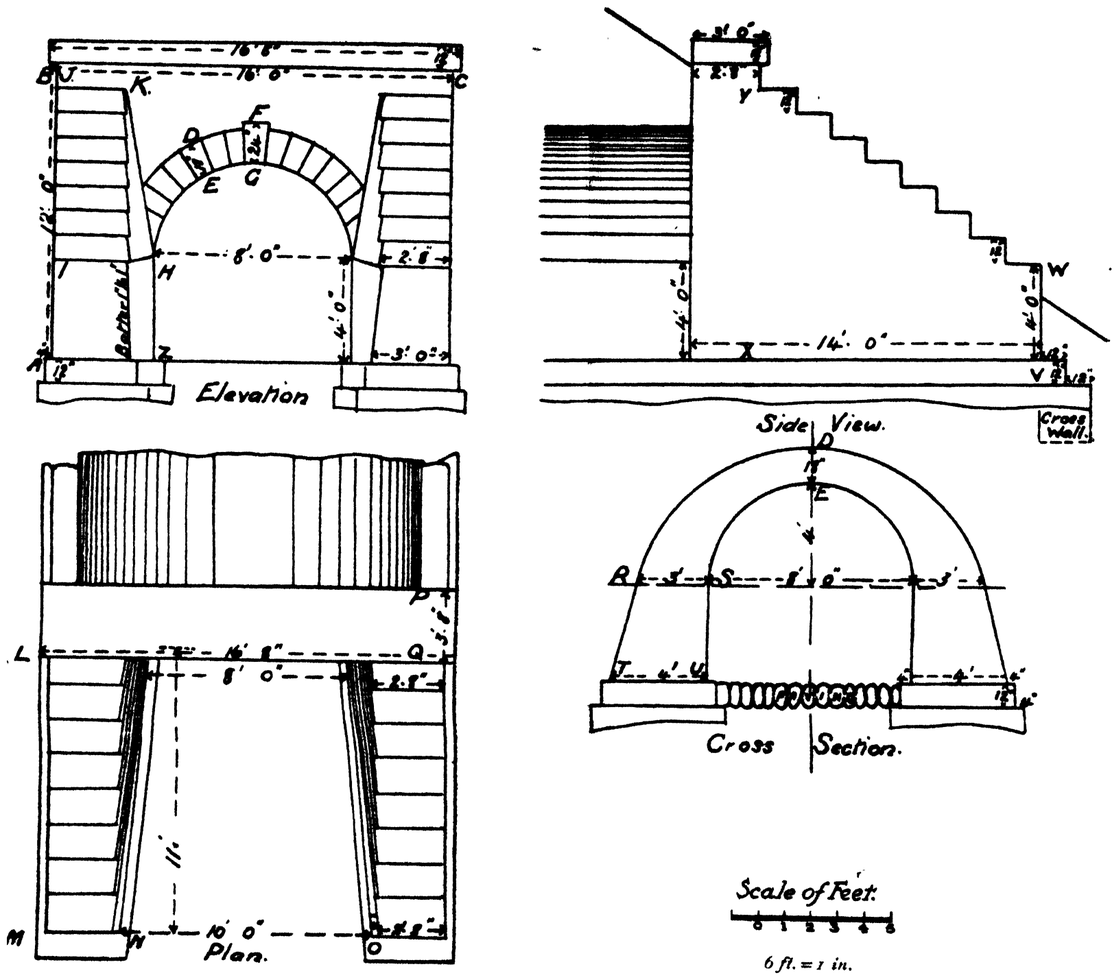
YEARS.	2	3	4	5	6	7	8	9	10	11	12	13	14	15 MARDAN	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33 SHERGARH
1895-96																																
1896-97																																
1897-98																																
1898-99																																
1899-1900																																
1900-01																																
1901-02																																
1902-03																																
1903-04																																
1904-95																																
1905-06																																
1906-07																																
1907-08																																
1908-09																																
1909-1910																																

REFERENCES:— COLLECTED METAL CONSOLIDATED METAL METAL COLLECTED AND CONSOLIDATED IN SAME SEASON

8-FT. ROAD-PROGRESS CHART.



8-FOOT ARCH CULVERT.



DIMENSIONS AND CONTENTS OF ARCH CULVERTS,

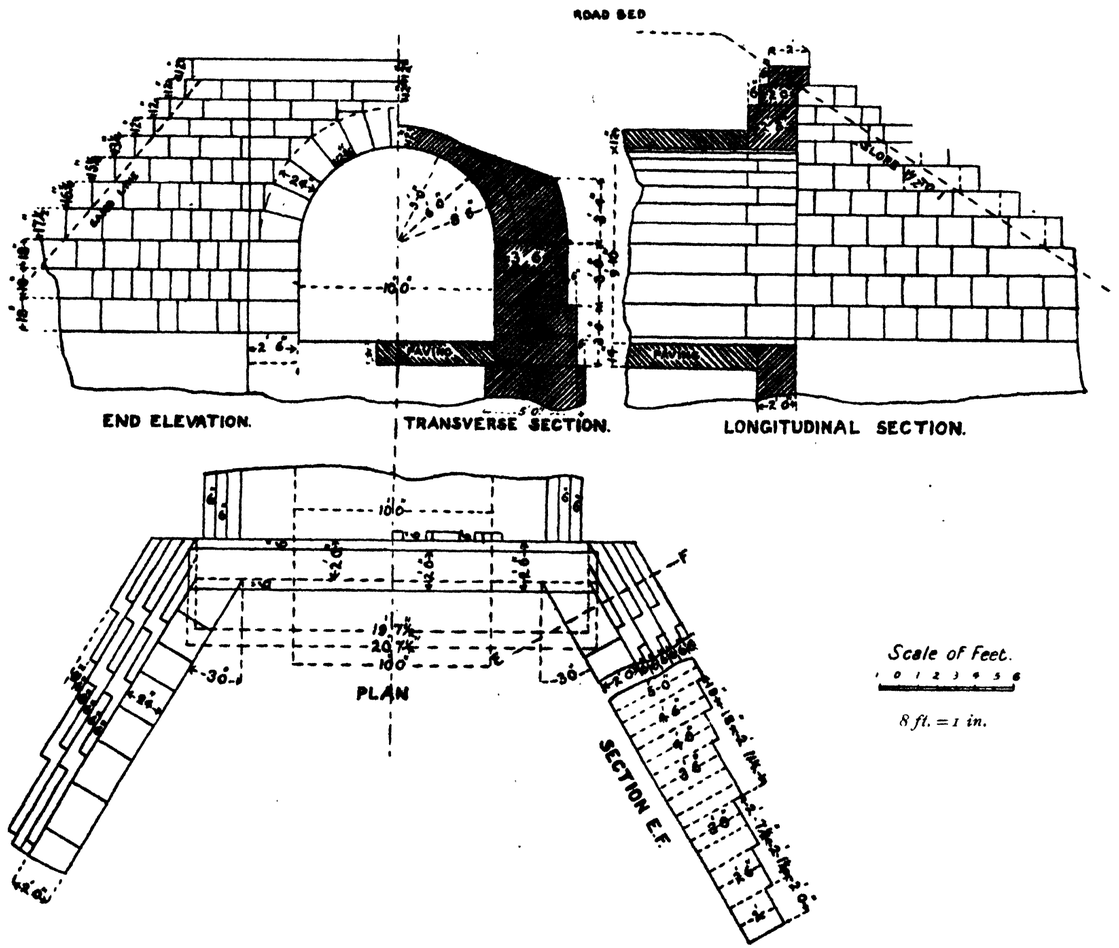
CHICAGO, KANSAS, AND NEBRASKA RAILWAY.

Dimensions not given in the Table are the same, for all sizes, as in the diagram.

ITEMS.	Designated in Diagram by	SPAN. 8 Feet.	4 Feet.	6 Feet.	9 Feet.	10 Feet.
DIMENSIONS :—		Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.
End wall, height above the footing	AB	6 0	9 0	11 0	12 0	13 0
,, length	BC	8 4	10 0	14 0	16 0	18 0
,, thickness	—	2 8	2 8	2 8	2 8	2 8
Coping on end wall, width	—	3 0	3 0	3 0	3 0	3 0
,, ,, length...	—	9 0	10 8	14 8	16 8	18 8
Wing, height at inner end	XY	4 3	7 3	9 3	10 3	11 3
,, ,, outer ,, ...	VW	2 0	3 0	4 0	4 0	4 0
,, length for slope of 1½ to 1	XV	4 10	7 10	9 4	10 10	12 4
,, thickness on top	JK	2 0	2 3	2 8	2 8	2 8
,, ,, at bottom of outer end	—	2 2	2 6	3 0	3 0	3 0
,, distance between outer ends of wings	NO	4 0	5 0	8 0	10 0	12 0
Arch, height of springing above footing	HZ	2 0	3 0	4 0	4 0	4 0
,, thickness at crown	DE	0 8	1 0	1 3	1 6	1 9
Side walls, thickness at springing...	RS	2 0	2 6	2 8	3 0	3 6
,, ,, top of footing	TU	2 8	3 0	4 0	4 0	4 6
Paving, depth	—	1 0	1 0	1 0	1 0	1 0
CONTENTS :—						
Four wing walls, including one footing course	—	7·7 c. yds.	19·7 c. yds.	35·5 c. yds.	40·5 c. yds.	53·4 c. yds.
Two end walls	—	10·6 ,,	18·2 ,,	30·1 ,,	36·8 ,,	44·2 ,,
Two side walls, including one footing course—per foot of length from inside to inside of end walls	—	0·592 ,,	0·882 ,,	1·333 ,,	1·382 ,,	1·567 ,,
Arch masonry, per foot of length from inside to inside of head walls...	—	0·270 ,,	0·478 ,,	0·791 ,,	1·184 ,,	1·712 ,,
Paving per foot of length from out-to-out of end walls . .	—	0·086 ,,	0·123 ,,	0·198 ,,	0·272 ,,	0·346 ,,
Coping on two end walls	—	27·0 c. ft.	32·0 c. ft.	44·0 c. ft.	50·0 c. ft.	56·0 c. ft.

NOTE.—Extracted from Ira O. Baker's *Treatise on Masonry Construction.*

10-FOOT ARCH CULVERT.



DIMENSIONS AND CONTENTS OF SEMI-CIRCULAR ARCH CULVERTS,

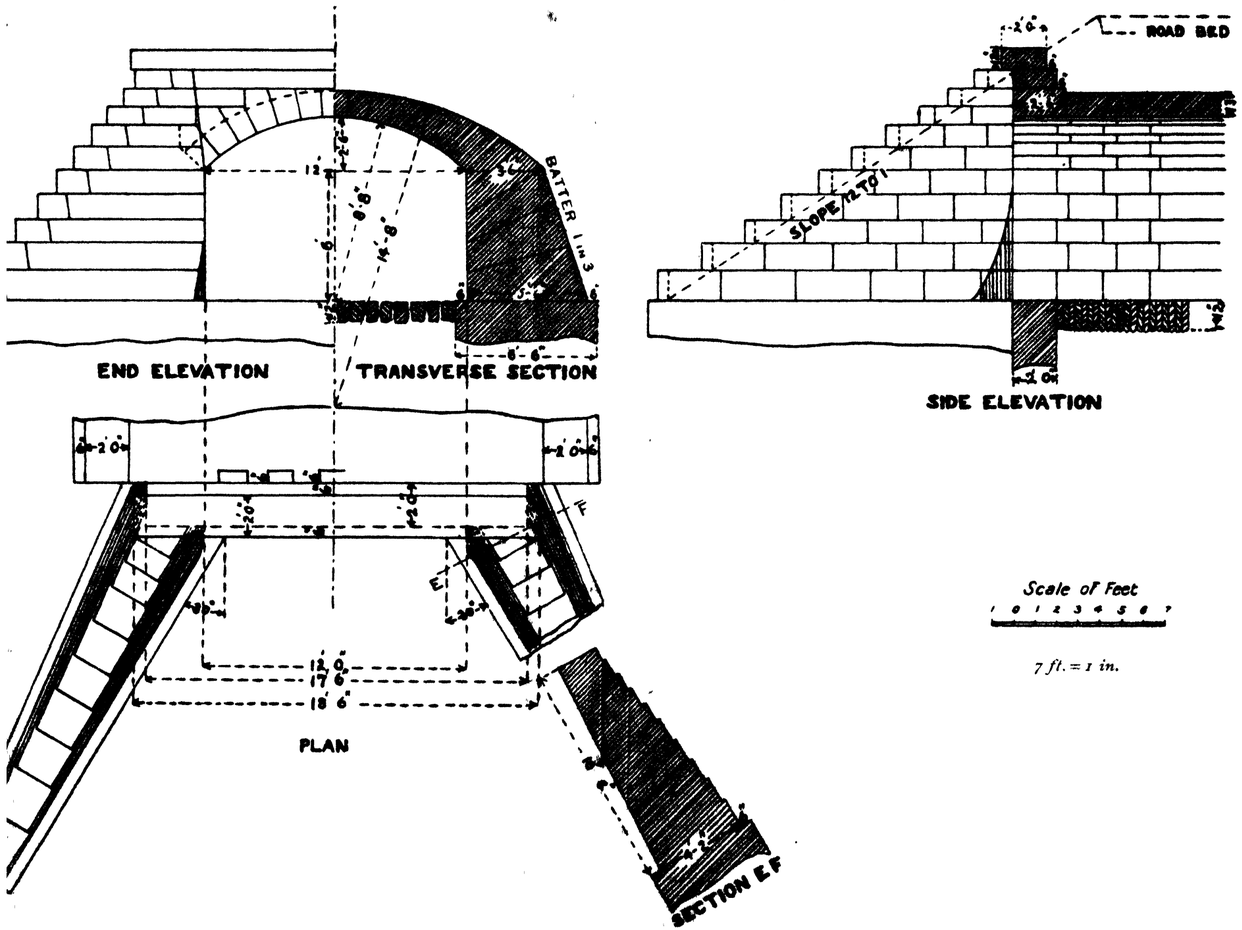
ATCHISON, TOPEKA, AND SANTA FÉ RAILWAY.

Dimensions not given in the Table are the same, for all sizes, as in the diagram.

ITEMS.	SPAN. 6 Feet.	8 Feet.	10 Feet.	12 Feet.	14 Feet.	16 Feet.
DIMENSIONS :—	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.
End wall, length	24 10	17 7½	19 7½	21 7½	23 7½	25 7½
,, height, top of footing to bottom of coping	9 11	12 8⅜	14 2½	14 8½	16 1⅜	18 3⅛
Coping, length	25 10	18 7½	20 7½	22 7½	24 7½	26 7½
Arch, thickness at crown	0 10	0 11	1 0	1 1	1 2	1 2
,, ,, springing	3 0	3 0	3 6	4 0	4 0	4 6
,, number of voussoirs	9	11	15	17	21	23
,, width of voussoirs at intrados ..	1 $0\frac{9}{16}$	1 $1\frac{1}{16}$	1 $0\frac{9}{16}$	1 $1\frac{5}{16}$	1 $0\frac{9}{16}$	1 $1\frac{1}{8}$
Side wall, thickness at springing	3 0	3 0	3 6	4 0	4 0	4 6
,, ,, top of footing ...	3 0	3 6	4 0	4 0	4 6	5 0
,, height of, above top of footing ..	3 6	5 0	6 0	6 0	7 0	8 0
Wing, length for slope of 1½ to 1	None	23 2	25 9	26 7	29 1	32 11
,, thickness at bottom of Section EF ...	None	4 6	5 0	5 6	6 6	7 0
CONTENTS :—						
Two end walls, above footing	30·92 c. yds.	22·95 c. yds.	28·53 c. yds.	28·17 c. yds.	30·12 c. yds.	35·64 c. yds.
Arch, per foot of length—inside to inside of end walls	0·765 ,,	1·072 ,,	1·469 ,,	1·935 ,,	2·274 ,,	2·807 ,,
Two side walls, per foot of length, inside to inside of end walls	0·777 ,,	1·213 ,,	1·666 ,,	1·777 ,,	2·140 ,,	2·783 ,,
Four wings, facing, slope 1½ to 1	None	46·00 ,,	56·88 ,,	60·74 ,,	72·35 ,,	99·14 ,,
,, backing, ,, ...	None	19·02 ,,	28·21 ,,	34·78 ,,	52·05 ,,	73·76 ,,
Paving, per foot of length—out-to-out of end walls	0·26 c. yds.	0·346 ,,	0·432 ,,	0·518 ,,	0·605 ,,	0·691 ,,
Coping on two end walls	103·33 c. ft.	74·50 c. ft.	82·50 c. ft.	90·50 c. ft.	98·50 c. ft.	106·50 c. ft.

NOTE.—Extracted from Ira O. Baker's *Treatise on Masonry Construction.*

12-FOOT STANDARD ARCH CULVERT.



DIMENSIONS AND CONTENTS OF STANDARD ARCH CULVERTS.

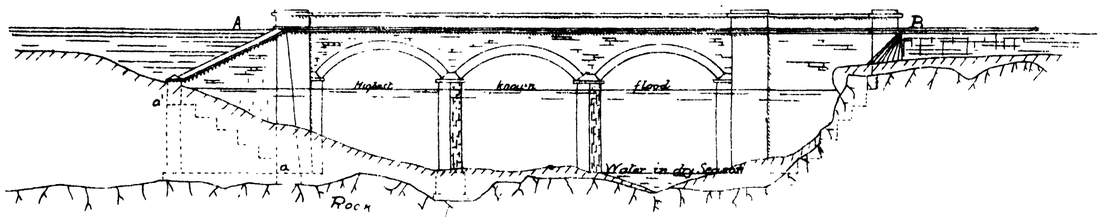
Dimensions not given in the Table are the same, for all sizes, as in the diagram.

ITEMS.	SPAN. 6 Feet.	8 Feet.	10 Feet.	12 Feet.	14 Feet.	16 Feet.
DIMENSIONS :—	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.
End wall, length	11 2	13 4	15 5	17 6	19 7	21 8
,, height, top of footing to bottom of coping	6 0	7 6	9 0	10 6	12 0	13 6
Coping, length	12 2	14 4	16 5	18 6	20 7	22 8
Arch, radius of intrados	4 4·2	5 9·6	7 3	8 8·4	10 1·8	11 7·2
,, ,, extrados	7 2	9 6	12 2	14 8	17 1	20 0
,, rise (= ⅕ of the span)	1 2·4	1 7·2	2 0	2 4·8	2 9·6	3 2·4
,, thickness at crown	0 10	0 11	1 0	1 1	1 2	1 3
,, length of extrados	6 7·4	8 9·9	11 4·1	13 2·9	15 5·4	17 7·9
,, number of voussoirs	7	9	11	13	13	15
,, width of voussoirs on intrados ..	0 11⅜	0 11¾	1 0	1 0¼	1 2¼	1 2½
Side walls, thickness at springing	2 0	2 6	3 0	3 6	4 0	4 6
,, ,, top of footing ...	3 0	3 10	4 8	5 6	6 4	7 2
,, height of, above top of footing...	3 0	4 0	5 0	6 0	7 0	8 0
Wing, length for slope of 1½ to 1	11 11	14 6	17 2	19 10	22 5	25 1
,, thickness at bottom of Section EF...	2 6	2 6	3 0	4 2	4 10	5 5
CONTENTS :—						
Two end walls above footing	6·671 c. yds.	9·022 c. yds.	11·001 c. yds.	13·828 c. yds.	16·545 c. yds.	19·337 c. yds.
Arch, per foot of length, inside to inside of end walls	0·354 ,,	0·504 ,,	0·692 ,,	1·000 ,,	1·297 ,,	1·661 ,,
Two side walls, per foot of length, inside to inside of end walls	0·555 ,,	0·937 ,,	1·407 ,,	2·000 ,,	2·679 ,,	3·469 ,,
Four wings, slope 1½ to 1	12·99 ,,	19·49 ,,	30·48 ,,	44·08 ,,	61·07 ,,	81·96 ,,
Paving, per foot of length—out-to-out of end walls	0·185 ,,	0·259 ,,	0·333 ,,	0·407 ,,	0·481 ,,	0·555 ,,
Coping on two end walls	48·67 c. ft.	57·33 c. ft.	65·67 c. ft.	74·00 c. ft.	82·33 c. ft.	90·67 c. ft.

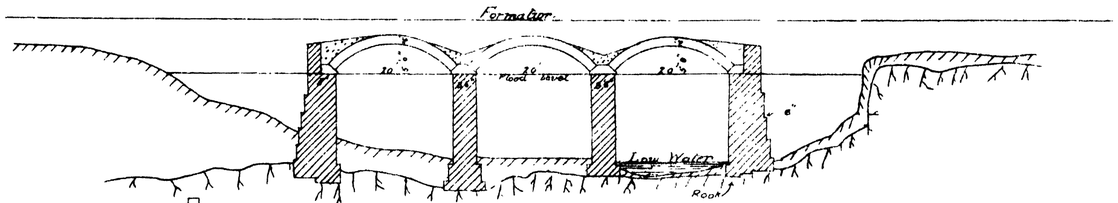
N.B.—In each case :—(*a*). Rise = span ÷ 5 ; height of opening = span ÷ 2 ; central angle is 87° 12′.
(*b*). Contents of wing walls are computed on the assumption that all courses are 1 foot thick.

NOTE.—Extracted from Ira O. Baker's *Treatise on Masonry Construction.*

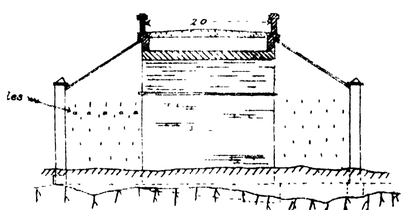
HILL ROAD MASONRY BRIDGE.



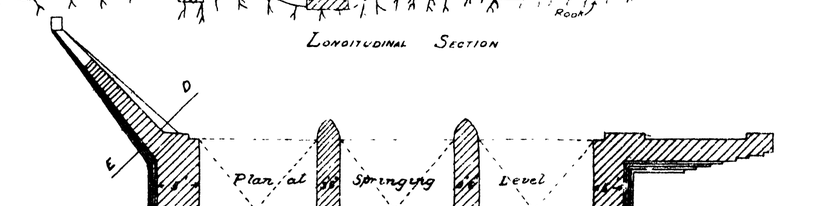
ELEVATION



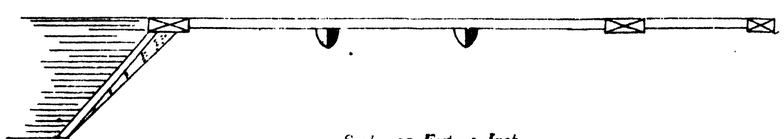
LONGITUDINAL SECTION



SECTION THROUGH CROWN OF ARCH.

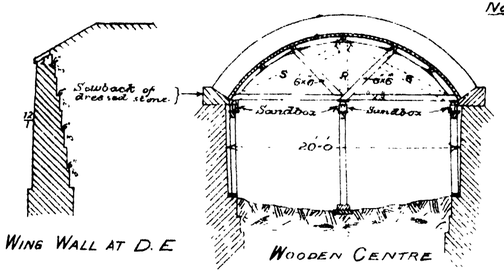


PLAN OF ROADWAY



Scale—20 Feet = 1 Inch.

PLATE X. (page 143)



SECTION OF WING WALL AT D.E

WOODEN CENTRE

Scale 10ft - 1 Inch

Note
Lagging 3"×2" stuff, 2" apart
Ribs 2 layers of 12×3 stuff, breaking joint.
When there is no central support add
King Post R and Struts S.S.

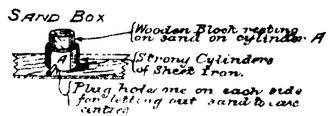
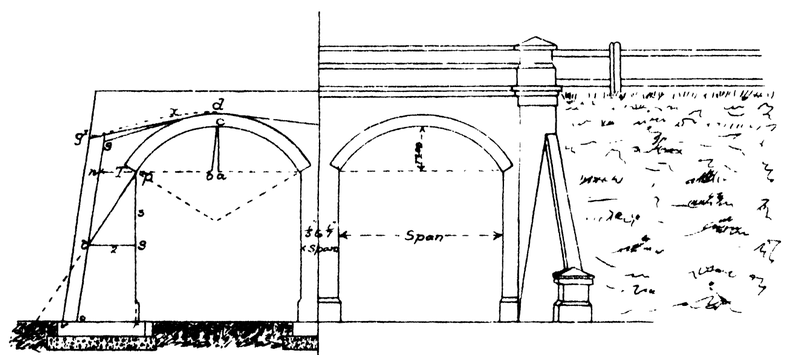


Fig. 3.

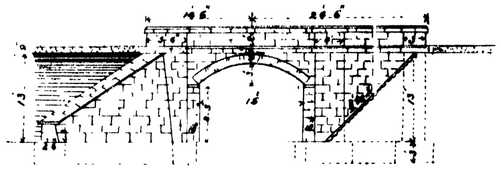


SECTION ELEVATION

15 FOOT SPAN BRIDGE.

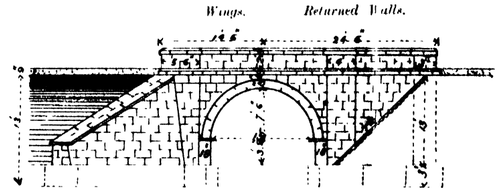
Segmental Elevation.

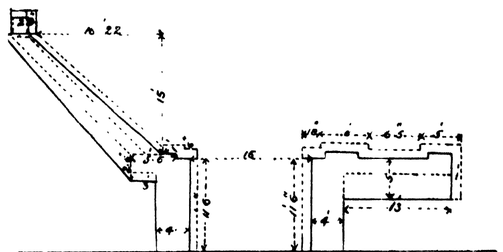
Wings. *Returned Walls.*



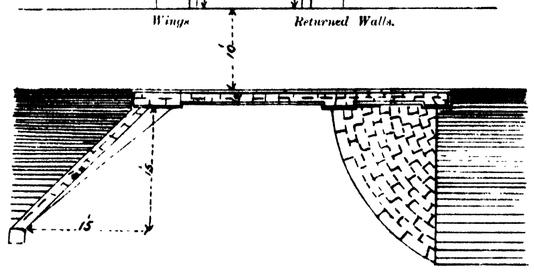
Semi-circular Elevation.

Wings. *Returned Walls.*





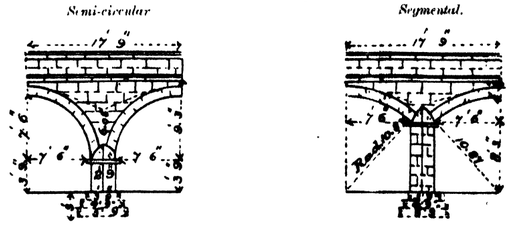
Wings *Returned Walls.*



Plan.

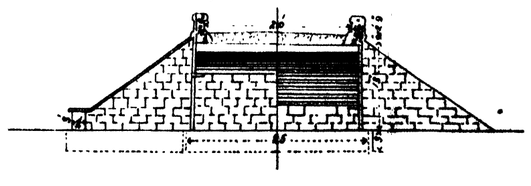
Each Additional Span.

Semi-circular *Segmental.*



Section.

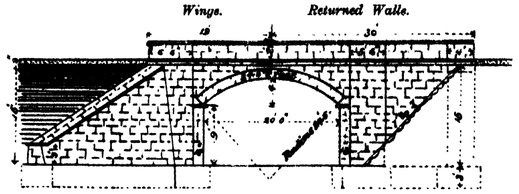
Wings. *Returned Walls.*



20-FOOT SPAN BRIDGE.

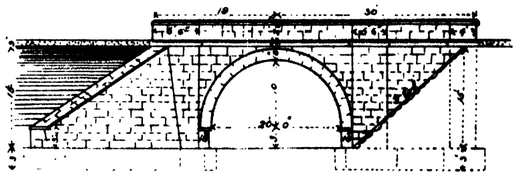
Segmental Elevation.

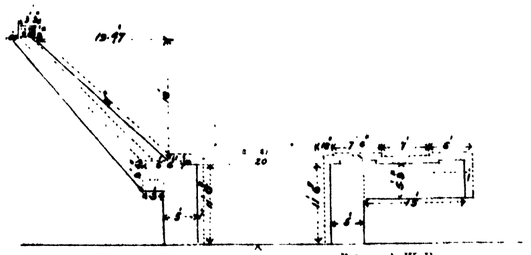
Wings. *Returned Walls.*



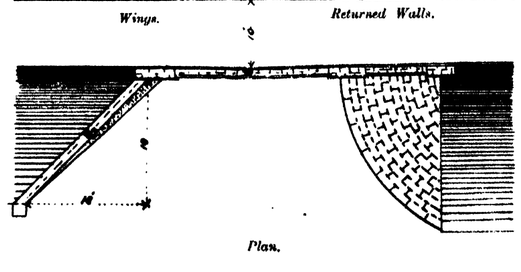
Semi-circular Elevation.

Wings. *Returned Walls.*





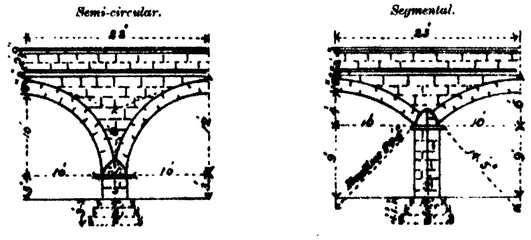
Wings. *Returned Walls.*



Plan.

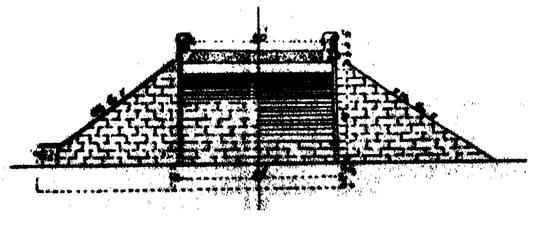
Each Additional Span.

Semi-circular. *Segmental.*



Section.

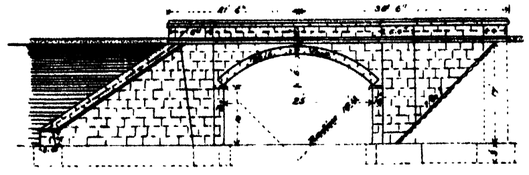
Wings. *Returned Walls.*



25-FOOT SPAN BRIDGE.

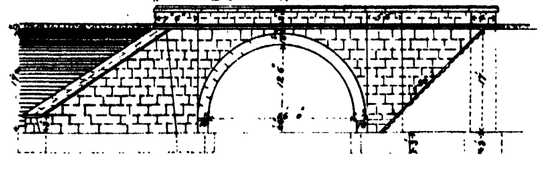
Segmental Elevation.

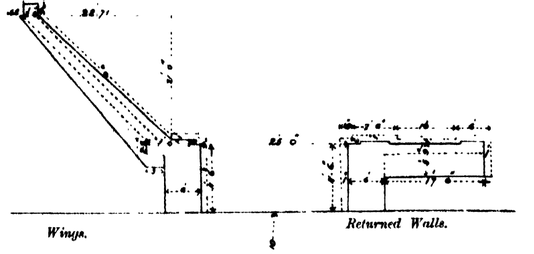
Wings. *Returned Walls.*



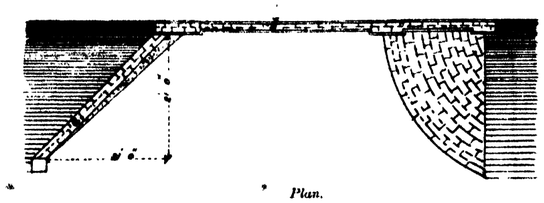
Semi-circular Elevation.

Wings. *Returned Walls.*





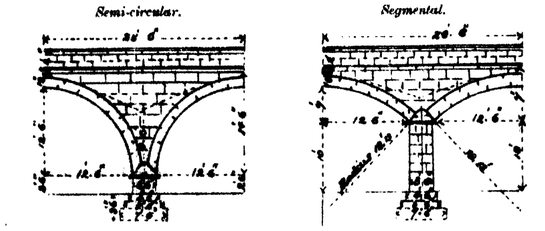
Wings. *Returned Walls.*



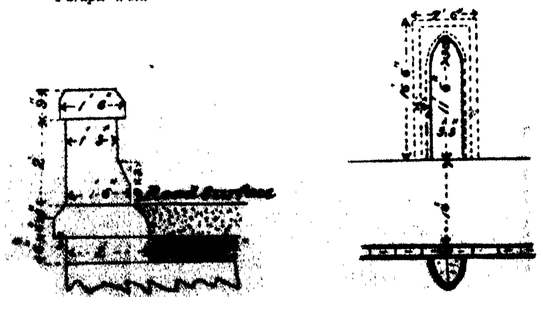
Plan.

Each Additional Span.

Semi-circular. *Segmental.*



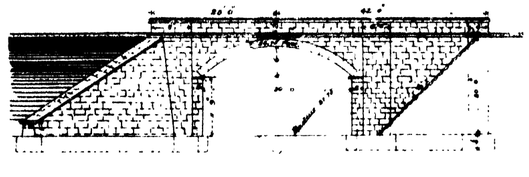
Parapet Wall. *Plan.*



30-FOOT SPAN BRIDGE.

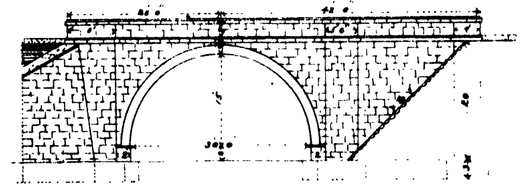
Segmental Elevation.

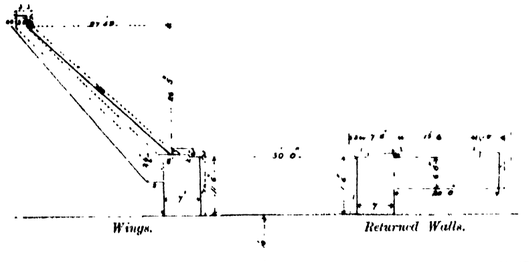
Wings. *Returned Walls.*



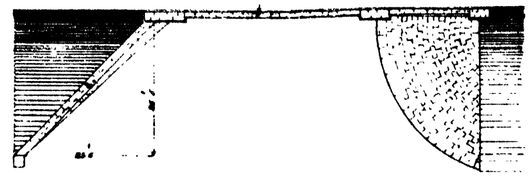
Semi-circular Elevation

Wings. *Returned Walls.*





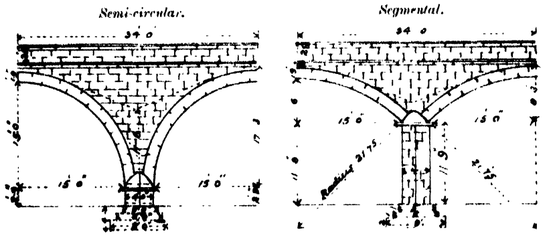
Wings. *Returned Walls.*



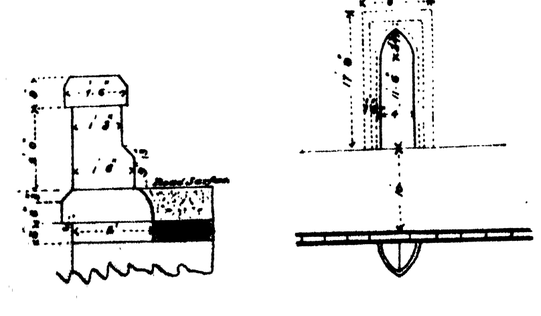
Plan.

Each Additional Span.

Semi-circular. *Segmental.*



Parapet Wall. *Plan.*



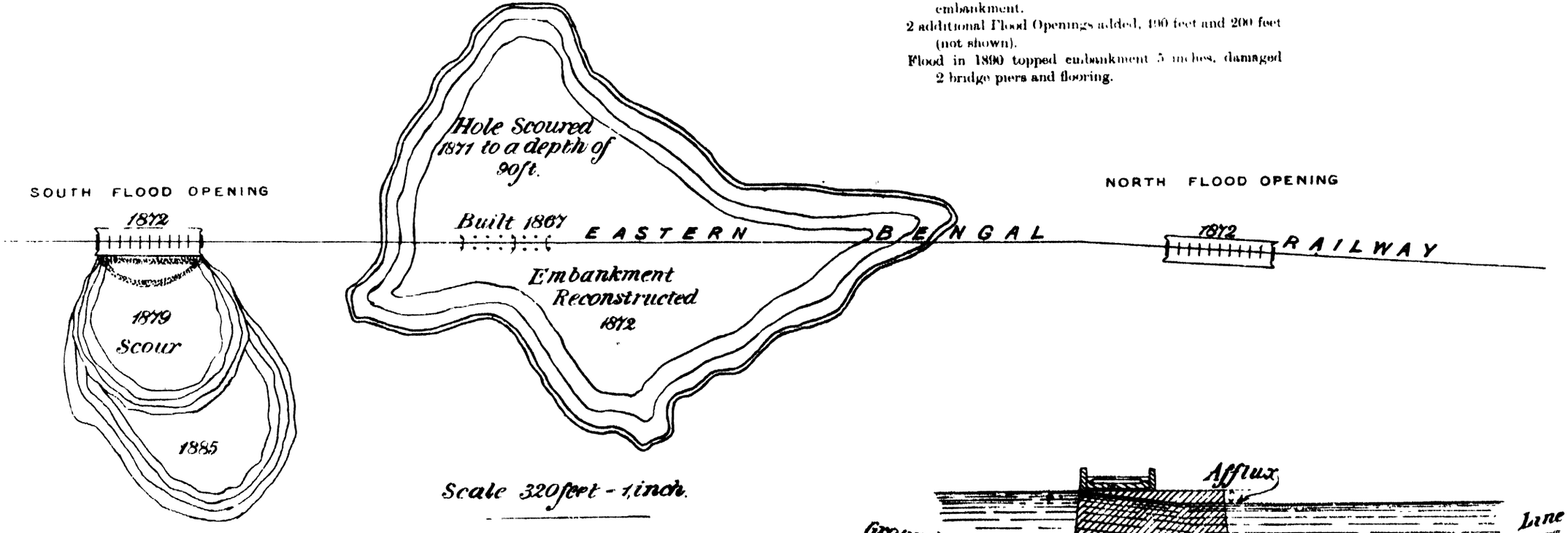
FLOOD OPENINGS, EASTERN BENGAL RAILWAY.

PLATE XII. *(page 138)*

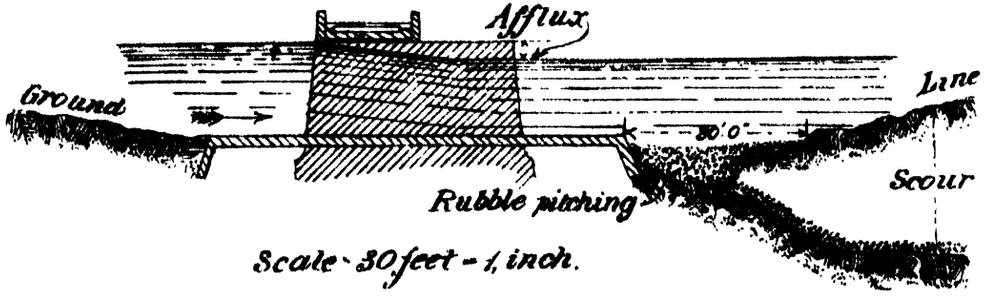


NOTE –

3 spans of 30 feet built 1867 Flood scour 7 feet
4 " " " added later Washed away 1871
Additional Flood Openings built 1872, N & S
Flood in 1879 and 1885 scoured deep hole and breached embankment.
2 additional Flood Openings added, 190 feet and 200 feet (not shown).
Flood in 1890 topped embankment 5 inches, damaged 2 bridge piers and flooring.

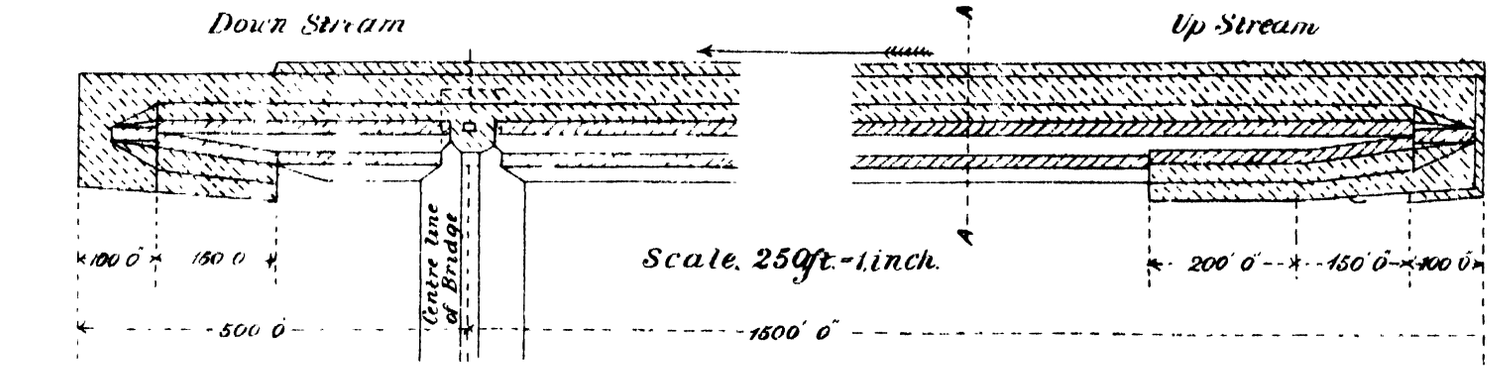


Scale 320 feet - 1 inch.



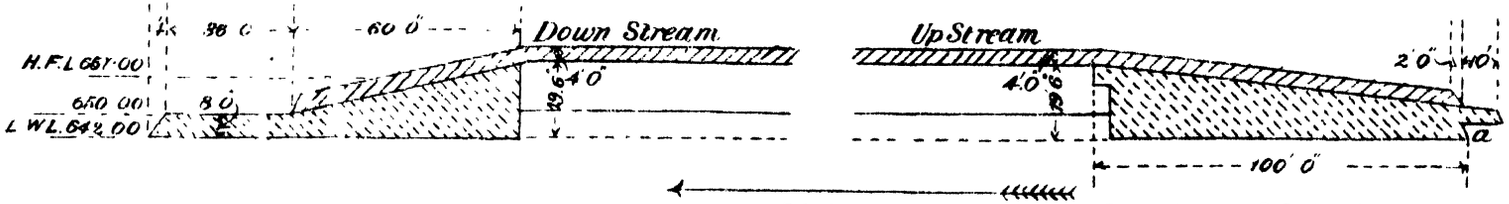
Scale 30 feet - 1 inch.

TYPE OF GUIDE BANK.



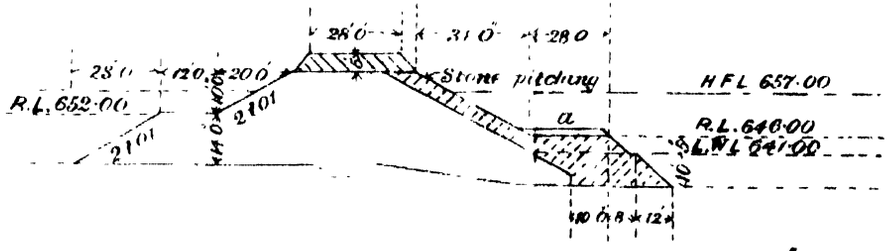
Scale. 250ft.-1 inch.

N.B.
Earthwork
Stone pitched
Stone (reserve)



Scale. 50ft.-1 inch

SECTION OF NOSE.



SECTION ON A.A.
(In Deep Water)

Scale 50 ft 1 inch

NOTE.

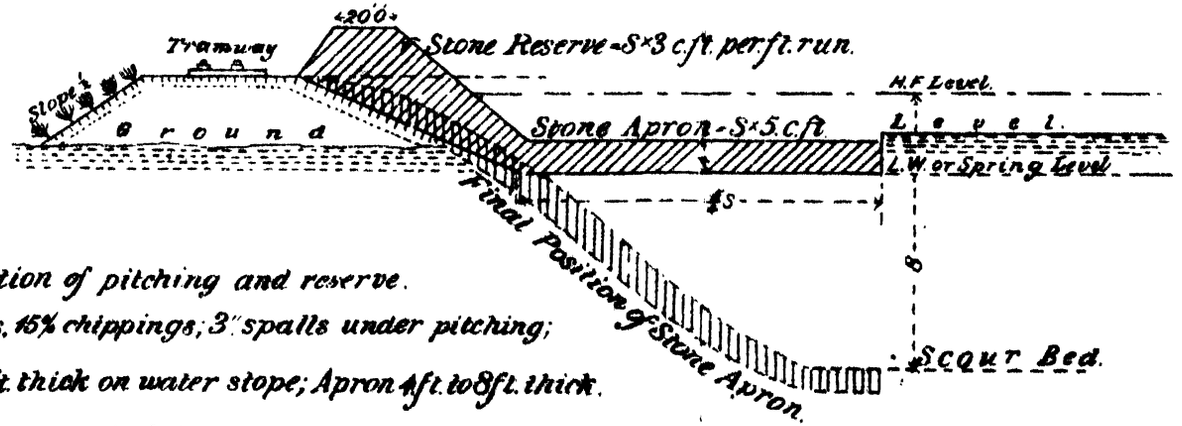
a a. Surplus stone after completion of pitching and reserve.

Specification:- 80 lb. stones, 15% chippings, 3" spalls under pitching;

Pitching 4 ft. thick on water slope; Apron 4 ft. to 8 ft. thick.

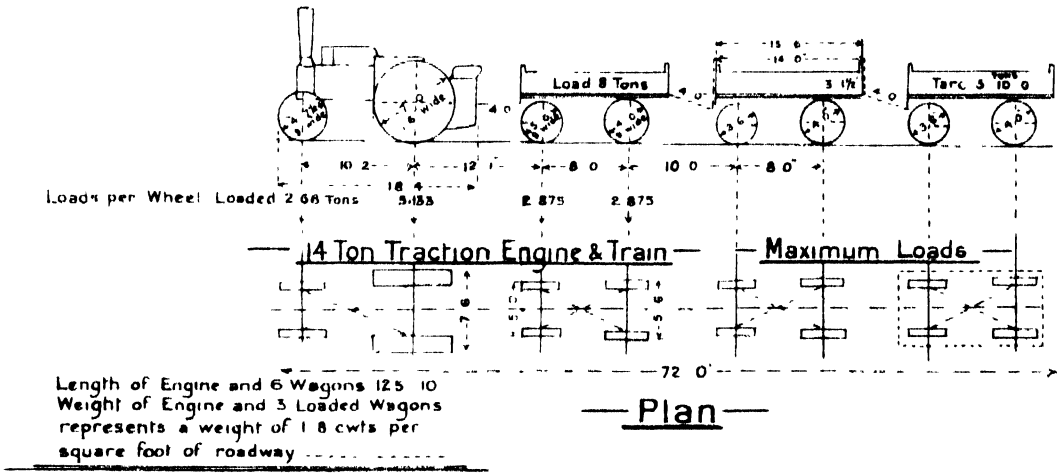
S = maximum anticipated scour in feet.

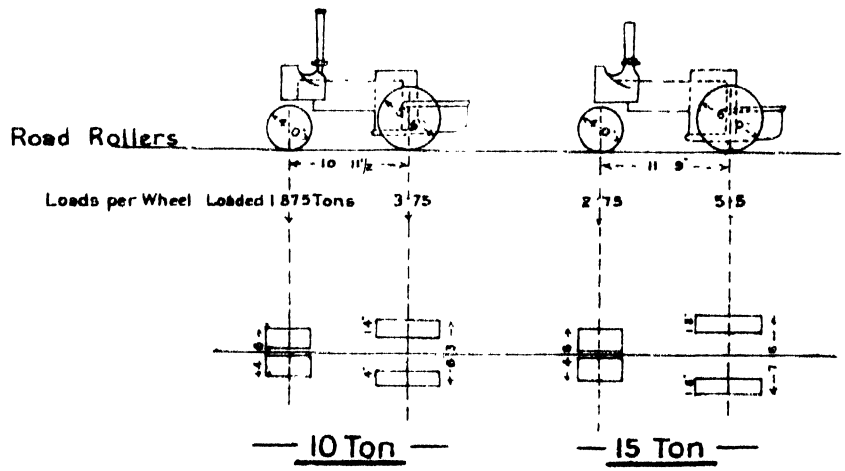
The Bank is formed from the excavation of the Apron pit.

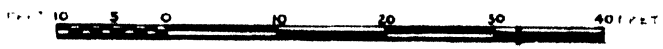


NORMAL SECTION OF BUND.

EQUIVALENT ROLLING LOADS FOR ROAD BRIDGES FOR CALCULATING STRENGTH OF GIRDERS.

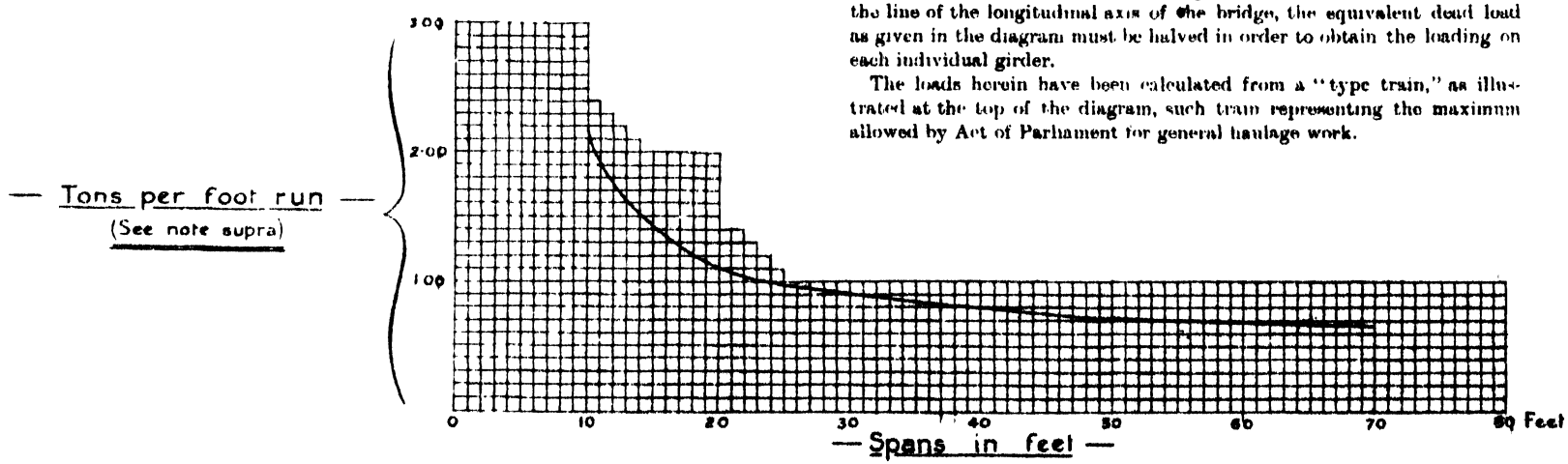






NOTE.—The spans in feet are taken from centres of bearings of girders. All calculations have been made on assumption that the whole weight of locomotive and train are borne by only one girder; the calculated distributed loads given on diagram must therefore be apportioned in each case between the main girders. For example, if a bridge is built with two main girders, and kerbs are placed so that the train must follow the line of the longitudinal axis of the bridge, the equivalent dead load as given in the diagram must be halved in order to obtain the loading on each individual girder.

The loads herein have been calculated from a "type train," as illustrated at the top of the diagram, such train representing the maximum allowed by Act of Parliament for general haulage work.



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Wood Block Flooring

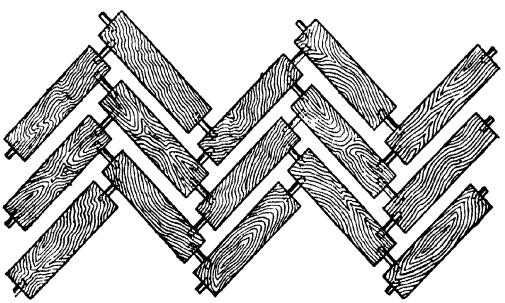
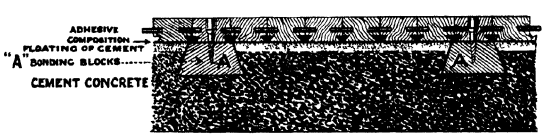


Diagram with Joints left open to show the method of Dowelling



Sectional View of W. DUFFY'S Immovable-Acme System of Wood Block Flooring.

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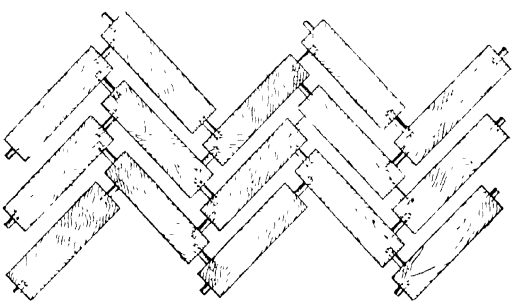
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W. DUFFY'S PATENT

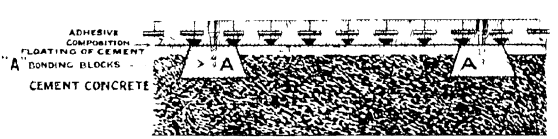
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Diagonal View of Portion of Floor Laid on Duffy's Patent



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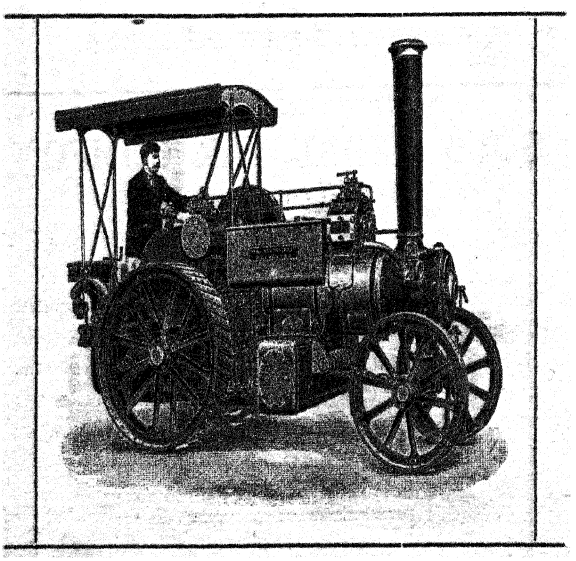
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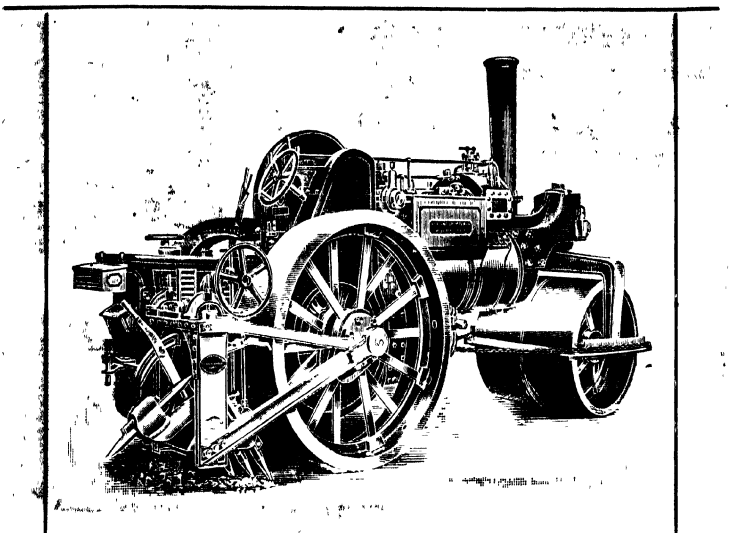
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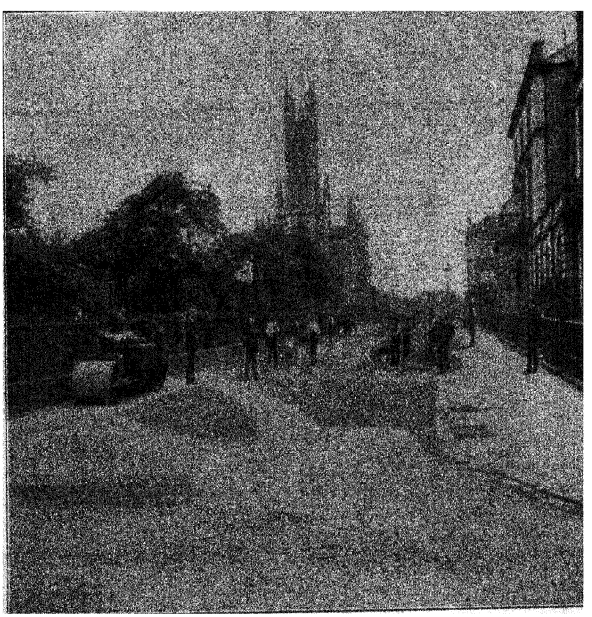
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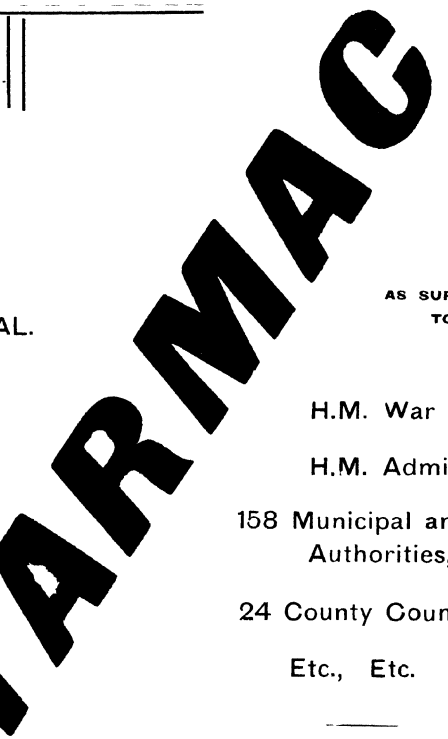
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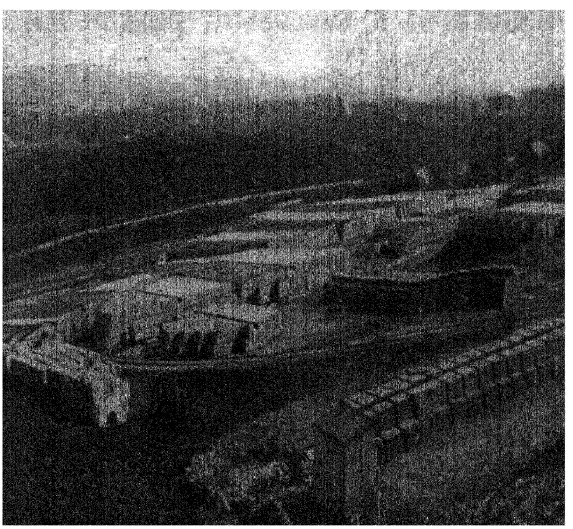
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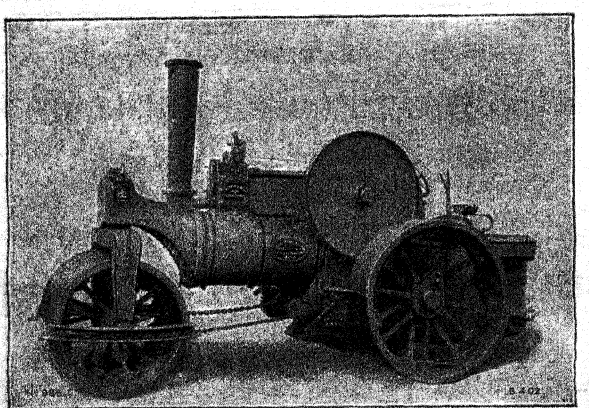
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These most powerful EXPLOSIVES of the Nitrate of Ammonium Class, now used by the largest railway and quarry contractors in Great Britain, combine in themselves the strength of the Nitro-Glycerine compounds with the safety of the Nitrate Classes.

No Exudation; No Freezing.

UNAFFECTED BY COLD OR HEAT.

Packed in hermetically sealed lever-lid tins of 5 lbs. each, to withstand rough usage and climatic influence. Tins can afterwards be used for canteen purposes.

Ammonal Nos. 3, 4 and 5

are used for rock blasting, military road making, mining and quarrying of all kinds.

Ammonal Grain.

A high explosive in grain form—a substitute for black powder, in concentrated strength. **1 lb. Ammonal Grain does equal work to 3 lbs. ordinary gunpowder.** Packed in 10-lb. tins, with screw nozzles; this explosive requires a detonator.

Full particulars of these explosives, the only ones containing Aluminium as a base protected by patents in all countries, can be obtained from the following agents of the Company, who can supply stocks ex local magazines:—

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And from the Head Office of the Company,

Ammonal Explosives, Ltd.,

29, Great St. Helens, E.C.

H. M. SAVAGE, Secretary.