

No. 1,319.—“On the Tracing and Construction of Roads in Mountainous Tropical Countries.” By Major JAMES BROWNE, R.E., Assoc. Inst., C.E.

THE object of this Paper is to put on record facts noticed, and precautions found necessary, whilst making roads through countries of which the physical features, as compared with England, are on a very large scale. For instance, the Hindustan and Thibet road is nowhere less than 5,000 feet above the sea, and reaches 16,000 feet. The Kangra valley cart-road runs for more than 90 miles across the whole drainage of mountains averaging from 18,000 to 24,000 feet in height; the annual rainfall of the district varies from 180 inches to 220 inches, of which 170 inches have been known to fall in the two and a half months of the rainy season, and $5\frac{1}{2}$ inches in one hour. The statements herein contained refer to Indian practice, and will not necessarily hold good for Europe, or even for other tropical countries differently circumstanced as to climate or geological formation.

Mountain roads can be divided into two classes. The one crosses or is taken along the main or higher ranges, the other over the lower or subsidiary ranges. Both have their peculiar features; but it is believed that the latter class generally presents the most serious engineering difficulties. This may at first sight seem unlikely, until it is remembered that some of the highest Himalayan passes, like that over the Chang-chenmo, consist of undulating downs, and that the rain-clouds from the plains, breaking against the first main ranges, and discharging on the subsidiary hills, do not generally reach the inner lines of mountains, and are quite unknown on the high table lands of Thibet. Again, in the higher ranges, the soil, being mainly composed of hard rock, does not allow every little channel to cut for itself a deep and ever-increasing chasm, as in the comparatively soft soil of the lower ranges, and renders the bridging

an easier matter. The great rocky cliffs of the upper Himalaya, though far more imposing, are not more difficult to deal with than the rotten gravel and clay ravines of the Sewalik and Salt Range; and are certainly far less dangerous cliff-climbing.

In the estimate here made of the relative engineering difficulty of road-making in the main and secondary ranges, cost is not included. The sub-Himalayan valleys, being amongst the richest and most thickly-peopled in India, can supply a fair amount of labour of all kinds; which has to be imported, at greatly increased cost, when works are carried out on the mountains above them.

The first thing to be remembered in the laying out and general planning of a mountain road is, that to no other kind of work is the motto "More hurry worse speed" more thoroughly applicable. No matter what amount of delay or labour may be entailed, the engineer should examine for himself every possible line; for no map of a really mountainous country, however admirably executed, can make up for personal knowledge. An old-established line of traffic should not be hastily abandoned for one that presents greater engineering facilities, and apparently equal commercial advantages. In a mountainous and thinly-peopled district local circumstances, which would never strike an engineer, are all-important to a native trader. For example, in one district of the Punjab a new road has been made from the hills to the plains, which, it was thought, would at once draw away all traffic from the old, circuitous, and greatly more difficult line. Far from it, however. The old road is used, and the new one is not, for the simple reason that, whereas both lines are thickly wooded, the trees on the new line are acacias and thorn bushes, and those on the old provide excellent forage, for five days' march, to the traders' beasts of burden. These and similar cases are of constant occurrence; and as in canal, so also in road-making, the natives of India have generally good economical and local reasons for the selection of their old lines of traffic.

The next thing to determine is the number of possible lines between the extreme points, and the main obligatory points on each. These are, first, towns and villages; and secondly, saddles or passes, which fix the general gradient. The total sum of rise and of fall between the common extreme points on each different line has then to be found, for which purpose a good aneroid barometer will give sufficiently accurate results.

There are many other considerations of expense—bridging, value of land, &c.—which must have their due weight in the selection; but there is no broad principle so generally applicable as this:

“The best line for a mountain road is that on which the total sum of the ascents and of the descents between the extreme points is the least.” This, though almost self-evident, is often disregarded without sufficient cause. Sometimes a deep river, chasm, or line of vertical cliff presents itself, and is regarded as an insuperable difficulty, it being forgotten that one great evil may be easier to overcome than a number of smaller ones. Nowhere is one so easily misled by appearances as on a mountain road; and the total sum of rise and of fall on any particular line affords an impartial and mechanical check upon the engineer's personal equation, to use an astronomical term, which should not be disregarded without valid reasons on other grounds.

At elevations exceeding 8,000 feet attention must be paid to the action of the snow in winter, as it is apt to be troublesome. The best approach, in an engineering point of view, to the station of Dalhousie lies through a ravine, which is, however, so sheltered from the sun, that the snowdrifts remain unmelted for weeks and bar the way; and it has been found necessary, in consequence, to take the new cart-road through otherwise very unfavourable ground. At Roksar, in Lahoul, a well traced road, but laid out in the height of summer, is impassable for the three spring months from incessant avalanches; one of which, $\frac{1}{2}$ mile in length, and exceeding 100 feet thick, carried off a stone bridge of 40-feet span, and remained unmelted for more than six months.

In finally laying out the work a few simple rules and precautions should be observed. In marking out the formation level, cuttings exceeding 10 feet or 15 feet in depth should as much as possible be avoided. In the stony soil of a hilly country no information is to be got by boring; and rock of the toughest and hardest description sometimes crops up where least expected. Where land, as in the mountains, is of little value, sufficient material for embankments is easily obtainable without having recourse to cuttings.

In the Himalayas, the northern slopes are thickly wooded, where the southern slopes are often quite bare. The wooded side should as a rule be selected, notwithstanding the increased labour of tracing through the brushwood, as the road will be more durable. The trees break the force of the rain as it falls, and the mould beneath them passes it off gently over the road, which, on the bare hillside, would be cut away by the unchecked rush of water.

Where the road-trace crosses a deep chasm formed by a river, the approaches should always be laid down stream, so as to get the

localities. Paved short cuts should be provided at all zigzags, for flocks of sheep and goats, which will otherwise do more damage than any wheeled traffic.

The original trace must be a good deal easier than the gradient intended for the completed road. The allowance to be made varies with the nature of the ground ; but in a general way

1 in 47	works down to	1 in 45,
1 in 37	”	” to 1 in 35,
1 in 28	”	” to 1 in 26,
1 in 22	”	” to 1 in 20,
1 in 19	”	” to 1 in 18,

or 5·55 in 100, which is usually considered the steepest admissible gradient for an unmetalled mountain cart-road in India. Where the trace rises steadily, the gradient must be broken at every 500 or 600 yards by 100 feet or less of slight counterslope, not merely to ease the cattle, but to break the drainage, which, on the cross drains happening to choke, causes great damage to one continuous slope.

In tracing a Himalayan cart-road, the fact should never be lost sight of, that length is the one thing sought for, to overcome the immense heights met with. Every possible foot of rise should be gained and never again lost.

As to instruments for tracing gradients along hillsides, for accuracy and rapidity combined, no clinometer or quadrant hitherto brought forward can equal an ordinary dumpy level, provided with telescopic legs for use in difficult ground. A properly collimated floating telescope, finding its own level without adjustments, would be a great boon to all engineers.

Having noticed these points in the tracing and original selection of a line, it will be well to pass on to the actual construction. The bridging is too large a subject to be entered into here ; and the remaining works can be classed under the following heads :

Excavation of Earthwork.

Retaining Walls.

Surface Drainage.

No attempt should be made, in the first season, to complete a road with neatly-dressed slopes and finished surface drains. In the Himalayas no earthwork takes its bearings, or becomes permanent, under two rainy seasons. Landslips occur with every shower and every hard frost, till they have worked them-

selves out. On the Dalhousie cart-road, the mere cutting out of the hillside to 14 feet in width determined a landslip upwards of 800 feet back from the edge of the road, and parallel to it for about 700 feet. Drainage cuts and retaining walls were made to secure the road, but all to no purpose. The landslip was at last left to itself, a party of workmen being merely told off every morning to help the rubbish over the road; and in the three rainy months the whole mass of earth, rock, and trees worked itself off, leaving a solid substratum of soil, and giving no further trouble. During the heavy rains from June to September 1871 a forest of deodars of several acres disappeared in one night, slipping down into the river Beas at the foot of the mountain. Under such circumstances it is useless to lay down in specifications certain angles of slope for different soils; and it is true economy to allow the rains to remove every shaky landslip and rotten bit before any kind of dressing of slopes and surface is attempted. It is discouraging to see the work of months buried in a few days, but it is a trial which an engineer must submit to before he can complete a Himalayan cart-road.

The whole proposed width of completed road should be cut out of the solid hillside. A few feet of extra width is readily and cheaply obtained from the made earth of the side cutting; but it is false economy, quickly found out in the first week of the rainy season. This does not, however, apply to a rocky hillside, with a gentle side slope, where, with a little rough building, half of the road may be carried on the rocks blasted out of the other half. The sides of cuttings and embankments having once taken their natural bearings are generally protected by turfing. Where, as is often the case, sods are not procurable, a successful method is to cover the slopes with a layer of about 3 inches of mud plaster, composed of earth, sand, and cow-dung, and then sow broadcast with American grass seed, which as a rule grows better in India than that obtained from England. In some districts boulder and slate pitching takes the place of turfing.

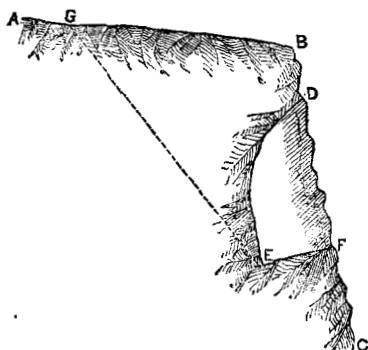
The vertical lines of cliffs unavoidably met with on the best traced lines present the most formidable obstacles. There are three different methods of forming a road along their face. The most expeditious is to establish a gallery, carrying the road on cantilevers of iron or timber. This plan, however, is only suited for mule or bullock roads, and is inapplicable for cart roads. It was originally largely employed on the Hindustan and Thibet road, but has since been replaced by half tunnels blasted out of the rock. As

these galleries are quickly constructed, and are useful in opening out temporary communications, it may briefly be explained how they are commenced. From the nearest possible standing point a gangway of lashed scaffolding poles is run out horizontally along the face of the cliff, the near end being held down by two leaded jumpers, or by lewisies let into the rock. A workman adventures himself to the farther end, and drives into the rock a jumper-hole, slanting about 45° , which, when sufficiently deep, receives an iron bar run with lead. To this support scaffolding is lashed, which acts as a new starting-point from which to advance another step. When the scaffolding so supported has extended along the whole length of the cliff, arrangements can be made for fixing the permanent cradles and cross-beams to carry the gallery. Where the cliff is not too long, time is saved by stretching a slight rope-bridge along the face, which affords good footing to a native cliff-climber, who prides himself upon venturing unassisted, wherever the rock is sufficiently rough to give a grip to the tips of his fingers and toes. Where, as on the Rogi cliffs, the vertical drop exceeds 1,400 feet, with about 4,000 feet of precipice beyond it, this driving of the first jumper-holes is nervous work. It is noteworthy that on the Hindustan and Thibet road all the most dangerous climbing was done by a Thibetan, who lived entirely on alms, refusing all pecuniary remuneration for what he considered a religious duty. The galleries were $7\frac{1}{2}$ feet wide, the supporting cradles being from 12 feet to 15 feet apart.

The other modes of forming a road along a cliff are, either by blasting in the usual manner, or by the use of mining galleries and large charges of powder. Blasting is a slow and tedious operation, and its prime cost is heavy; but once done, the work may be trusted to give comparatively no further trouble. The small charges bring down just what is required, leaving the rock sound and free from shakes. Great mines do the work far cheaper, far quicker, and almost at a blow; but no care or experience can prevent the cliff being occasionally so shaken as to cause incessant slips, continuing sometimes for years, and the road so easily formed comes, in the long run, to be rather expensive. The engineer must, however, determine, in each particular case, where he must blast, and where mine. For example, in Fig. 2, if A B C be the section of the cliff, and the rock be sufficiently hard and stiff, he can blast out a half tunnel like D E F; but if it be too soft and rotten to admit of this, the best plan, if B F be any great height, is to blow out the whole piece G E F by a large mine

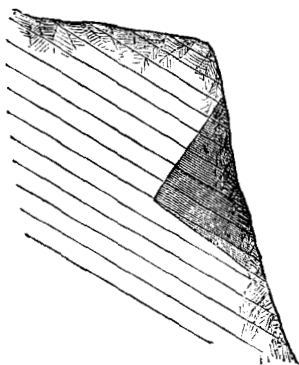
at E. Mining should not, as a rule, be employed where there is any chance of the powder acting in the direction of the dip of

FIG. 2.



the strata, as the result is to blow out a piece, as shown by the shaded portion (Fig. 3), which, before it can be rectified, entails

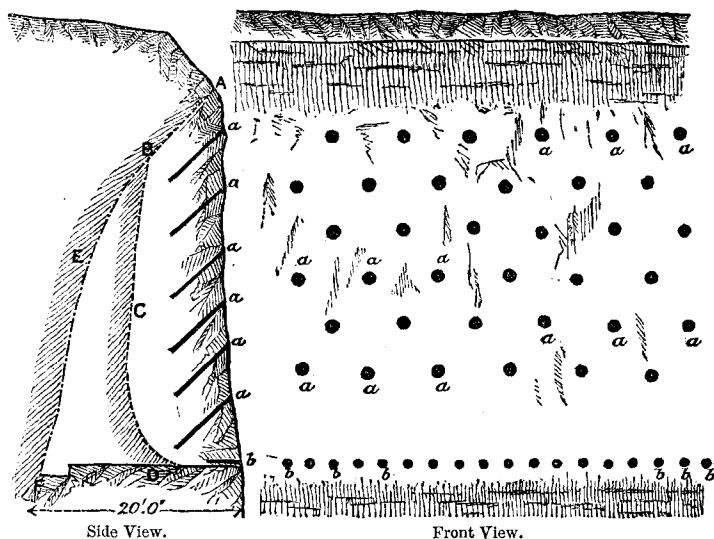
FIG. 3.



much labour and expense. There are cases, however, where the half tunnel could not be used, and where the brow of the cliff is so high above the proposed road-level that the cost of blasting out the whole piece is prohibitive. Here there is no help for it, whatever be the lie of the strata, but to try the effect of heavy mines.

The general mode of attacking a vertical cliff, and of forming a half tunnel, is shown in Fig. 4. The large blasts, *a, a, a*, driven

FIG. 4.



8 feet in depth, at an angle of 45° , are 7 feet 3 inches apart horizontally and 5 feet vertically, disposed checkerwise. The small holes, *b, b, b*, 3 feet apart and 3 feet deep, are not fired, but merely serve to determine and facilitate rupture at the proper level. These blasts when fired, as far as possible simultaneously, generally blow out or loosen a piece like *A B C D*. The remaining space, *B E F*, is dealt with in the same manner. Nitro-glycerine, being merely tamped by pouring water into the blast holes, has a great advantage over gunpowder as an explosive in such inaccessible situations; but its tendency to freeze renders its use dangerous at great altitudes.

Where kunkur rock is met with, special cartridges are employed for blasting. This substance, a kind of limestone conglomerate, is best described as exactly resembling petrified sponge, which, whilst allowing the powder to blow out through its pores, is so hard and tough as to defy the best steeled picks and jumpers. These cartridges were originally made of cast iron; but afterwards of four thicknesses of the stoutest tin plate solidly put together, a small hole being left in the top to receive the priming needle. When loaded with fine grained powder they gave the most ex-

cellent effect, confining the explosive gases, and tearing off huge blocks of the kunkur.

On one section of the Hindustan and Thibet road, adjoining the glaciers, and where wood fuel was abundant, the use of blasting was abandoned for over a year in favour of wood furnaces. The rock, when intensely heated, and then quickly deluged with snow water, was found to break up and crack, with a great saving of time and labour. This plan has, however, since been abandoned, the fuel having been almost exhausted.

The chief difficulty in dealing with native quarrymen, who are otherwise generally well up to their work, is to prevent their wasting time and powder in sinking shallow blast holes. The ordinary daily task of boring per man is about 60 inches in sandstone or conglomerate, 45 inches in limestone, and from 30 inches to 32 inches in granite.

In attacking a cliff with large mines, a line of scaffolding was first erected along the whole face, and tunnels were driven into the rock, chambers being formed at the ends of return galleries to the right and left. The charges were placed at a horizontal distance from the cliff face of 2 feet more than the proposed width of the road, and generally blew out the rock on both sides to a distance equal to their line of least resistance. The best charges, in feet and pounds, were after many trials found to be :

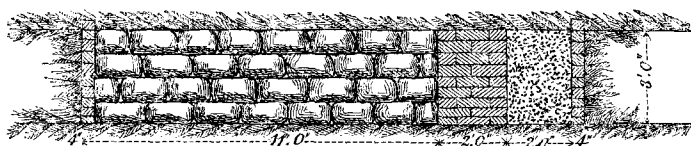
For granite or gneiss	$\frac{L. L. R.^3}{8}$
For limestone or hard sandstone . . .	$\frac{L. L. R.^3}{10}$
For conglomerate or slate shale . . .	$\frac{L. L. R.^3}{12}$

For instance, to form a road 20 feet wide, a gallery was driven 22 feet into the rock; then two returns of 22 feet each on either side. A charge of $\frac{2}{3}\frac{3}{8}$, or 1,065 lbs. of powder being lodged in each chamber, blew out a length of cliff of 88 feet by 22 feet in width. The galleries, which were 3 feet high by 2 feet 6 inches wide, could, in conglomerate rock, be driven at an average rate of 1 inch an hour, and at a cost of about 2s. per lineal foot. The rate of progress was three times and five times less in limestone and in granite than in sandstone rock or conglomerate, which rendered mining a tedious operation. The galleries, for the most part, were chiselled with cold steel and not blasted out.

The quickest, cheapest, and most effectual mode of tamping

mines in such impracticable localities was by using sandbags made of date or palm-tree matting, and containing about $\frac{1}{2}$ cubic foot of damp clay. With these, and a few half bags and quarter bags, the tamping was built up by native masons like an ordinary wall. At every 10 feet or 15 feet, according to the length of the mine, the galleries and returns were cut off by scantlings, 4 inches by 4 inches dropped into grooves cut in the rock. When the sandbag tamping had reached to within 4 feet of one of these doors, a wall 2 feet thick of ordinary sundried brick in mud mortar was built up vertically. The baulks being then slipped into the grooves, the intermediate 2 feet space was completely filled from above with fine dry sifted sand. The arrangement is shown in

FIG. 5.



Cushions of sand greatly increased the effect of the explosion. This systematic method of tamping could be done at the rate of 12 lineal feet an hour, or three times the rate of tamping with earth, in the usual and far less effective manner. The majority of the matting bags were, after an explosion, uninjured, and available for further use.

It has been found that great mines fired successively give much trouble in subsequent clearing, and occasionally explode uselessly through unnoticed fissures produced by previous explosions. Complete sets of mines were therefore generally fired simultaneously; nor was this attended in practice with any difficulty. At the Triloknath junction, on the Kangra valley road, two charges, each of 8,000 lbs., and fourteen charges, each of 1,600 lbs., altogether nearly 18 tons of gunpowder, were fired simultaneously with ordinary hose and Bickford's fuze, without any perceptible difference in the time of explosion. The effect was to bring down a cliff about 1,200 feet in length, and averaging from 300 feet to 400 feet in height. Each pound of powder dislodged about 200 cubic feet of conglomerate rock. The road was there formed at a cost for excavation of 7s. for 1,000 cubic-feet, which, if done by ordinary blasting, would have cost between 24s. and 28s. In limestone cliffs, each pound of powder could be expected to blow out about 115 cubic feet; in granite, not more than 75 to 85 cubic feet.

In blasting, but more especially in mining operations, it is often expedient to adopt some rapid but safe means of clearing off the huge masses of loose rock and earth, which, after an explosion, are too dangerous for men to work on, and too heavy to be dislodged. A few loaded 24-pounder howitzer shells placed under or behind these loose masses, and fired with a fuze, will seldom fail to bring them down, and to allow the work of clearing off to be safely commenced, which would otherwise be greatly delayed.

Dry masonry retaining walls are largely employed on most Himalayan roads, many of them being of great dimensions and of some constructive difficulty. As an instance may be quoted the wing-walls of a bridge, 350 feet in length, 70 feet in height, and built of split granite boulders, laid perfectly dry. The walls are on a curve of 50 feet radius, and are brought up on a batter of 1 in $4\frac{1}{2}$, with all the neatness of a brick wall. In the Western Himalayas the builders of these walls form a large hereditary caste, and it is remarkable to observe how, from long practice, but with the rudest implements, they will handle and accurately place unhewn stones weighing 4 or 5 tons at great heights, and in the most dangerous localities.

The use of sandstone is a frequent cause of failure in retaining walls, and, notwithstanding its clean splitting and good bedding, it is by no means so desirable a material for such work as granite or limestone boulders. The difficulty is to obtain sandstone which, however hard and durable it may seem at first sight, will not disintegrate under the tropical rains in damp situations, as in foundations below the level of the ground, and not exposed to the air. Retaining walls of what seemed most compact sandstone have suddenly collapsed, the underground courses having dissolved into sand. It is therefore usual to construct such walls, from the foundations to 2 feet above the ground line, with granite boulders, the rest of the wall being built of sandstone, which should, however, be as seldom as possible employed.

Next to the quality of the stone, the chief thing to be attended to in a dry retaining wall is to prevent the workmen giving fair outer facings of large stones, and filling them in with irregular chips. The proper specification for such a wall should be: "Each horizontal layer to be laid in regular courses throughout the wall from the outer to the inner face."

Many engineers employ timber framing at every 5 feet or 6 feet in height of the retaining walls. The stability is, no doubt, most materially increased; but, in such a rainy and intensely damp climate,

the wooden framing introduces into the wall an element of decay, and its use, although general, cannot be recommended.

Where expensive masonry in mortar is used, great economy will result from the best possible shape and dimensions being given to retaining walls; but where cheap dry masonry is employed, two simple rules will suffice for all practical purposes. The first, and probably the more important one is, never to use earth of any kind for the backing of a wall, but to fill in the space entirely with boulders or stone chips. This is sometimes rather expensive, but it has been amply proved by endless failures that, with such rainfalls, no care in ramming or previous wetting will ever save a dry masonry revetment from being blown up by an earthen backing. The second rule, which has been found to work well in very rainy districts like Kangra, is to make all retaining walls, whatever their height, 2 feet 3 inches thick at the top, with a batter of 1 in 4 on the outside, and 1 in 8 on the inside. In less rainy districts, a width of 2 feet 3 inches at the top, vertical at back, with a batter of 1 in $4\frac{1}{2}$ to the front, has been found sufficient.

Great attention is required to secure good foundations for retaining walls; and rock or hard clay should be chiselled or blasted out into steps, vertical to the proposed front slope of the wall. Its foot should be protected by boulder pitching, extending outward from 5 feet to 20 feet; the water from cross drains being thrown well clear, by means of wooden troughs or stone slabbing.

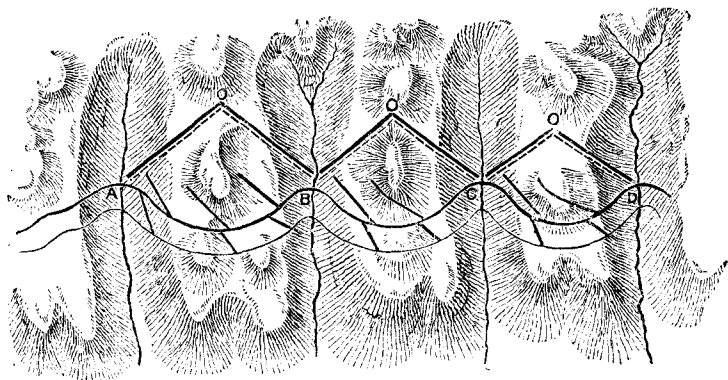
Revetment walls of masonry in mortar are seldom used, except when carrying the road along the edge of a hill torrent, and under a vertical cliff. This mode of construction is, however, more costly and less durable than blasting out of the solid rock. Dry walling, with masonry counterforts to break the force of the stream, has been used in such localities, but with no great success.

The mere excavation of a wide road along a hillside at once alters the whole system of natural drainage. It is useless to commence any drainage works until the annual rains have marked out the line of discharge across the great catchwater formed by the road. This naturally entails some damage; but many an expensive culvert has been built in a wrong place, which would have been saved at the cost of a chain or two of cheap earthwork. Drains or bridges can then be confidently built at those points (marked A B C D in Fig. 6) which, together with the great V-shaped drains A O, O B, O' B, O' C, &c., complete the main drainage system of the road.

The secondary drainage system, carrying off the rainfall within the V catchwaters, and on the road surface, consists of the side

drain along the road, the drains across and under it, and the smaller catchwaters above it.

FIG. 6.



The dimensions of the main V drains A O, O B, O' B, O' C, &c., naturally vary considerably. On some parts of the Lahore and Peshawur road they are 25 feet wide by 5 feet deep. On the Kangra road they average 10 feet wide by 3 feet deep; and it may generally be laid down that they should never be less than 6 feet wide by $2\frac{1}{2}$ feet deep. Where the side slope is great, their floors and sides are protected by rough slate slabbing, boulder paving, or fascine revetments. In crossing the great moraines, or landslips of loose shale, the road can only be secured by double lines of such V drains, revetted with three rows of crossed and pegged fascines. These rapidly get clogged with clay silt, and form an impervious yet slightly flexible channel to carry off the drainage, which would otherwise cut away the shale like loose sand. Whilst on this subject, it may be noted that fascine foundations, on the Chat Moss system, are much used to carry the road across the great peat bogs met with in the lower valleys.

There can be no greater mistake than, for reasons of economy, to construct small drains of any kind for mountain roads in tropical climates, as they are certain to choke up on the first shower. The smallest secondary drain should not be less than 2 feet by 1 foot 3 inches; no cross drain, if provided with a movable slab top, being less than 2 feet by $2\frac{1}{2}$ feet, or, if permanently covered in, less than 2 feet 3 inches by 2 feet 9 inches. To insure proper scouring, and an easy change of direction for the water, the cross drains have a floor slope of 1 in 12, and are built at an angle of 135° with the side drain, their ends being properly secured by boulder pitching.

The number of cross drains varies from 1 in every 120 feet in very rainy districts like Kangra, to 1 in every 300 feet in drier localities. Where the cross drainage is heavy, it is necessary to adopt saucer drains of coarse rammed concrete, 18 inches thick, supported by a retaining wall, and from 10 feet to 16 feet wide, with a depth of from 1 foot to 1 foot 6 inches. In the dry season this depression is filled in flush with the rest of the road. In the rains the earth gets washed away, and the concrete saucer does duty as a drain, presenting no obstacle beyond a jolt to a passing cart.

The main drainage is carried across the road through culverts, but more especially through large outlets in dry masonry retaining walls, covered in by stone slabs of from 2½ feet to 3 feet span. The requisite waterway is obtained by having several of these outlets, as also by the increased heights of the sides. For larger spans, up to 10 feet, and where slate is procurable, a dry rubble stone arch, built of picked stones neatly radiated and wedged up, is, whilst much cheaper, quite as strong and reliable as arching in mortar. Where building stone is scarce, concrete arches on dry masonry abutments are largely employed, the whole mass forming a monolith, rammed up in 4-inch horizontal layers. The usual composition of this concrete is—1 by measure of lime, 1 of sand, 1 of pounded brick, and 4½ of broken stone. With mortar masonry, or live rock, abutments, large spans are covered in by such concrete arches. The Durroon Bridge, on the Kangra road, is 48 feet span in the clear by 20 feet wide. The arch is entirely composed of rammed mortar, consisting of 1 part of boulder lime, 1 part of pounded brick, 1 part of sand (largest grain the size of a pea), no broken stone whatever being used. A specimen of this mortar, carefully tried in a testing machine, was found to crush under a power of 4,032 lbs., say 1·8 ton per square inch, Portland cement yielding under 0·45 ton. Besides being cheaply and quickly constructed, such a bridge has the great advantage in remote localities of requiring no skilled labour except for the centring. In this operation arrangements for striking can be dispensed with, as the concrete arch when setting expands, and lifts itself off the lagging.

The necessary waterway for large culverts depends very much on the nature of the foundations, and is probably more a matter of experience and observation than of calculation. As to the amount of rainfall over the catchment basin, there are many opinions; but the practice in the Kangra district has been to provide for 5 inches an hour over areas not exceeding 1 square mile; and this allowance, although sufficient, has not proved excessive.

[1873-74. N.S.]

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Drainage should never be estimated by the floods, however severe, occurring during the first month of the rainy season. In tropical climates the three months of dry, hot weather preceding the rains so parch up the earth that the first floods of the season, however steep the hillside, are no criterion of what will happen when the soil has become thoroughly sodden, and cannot absorb additional moisture.

Marks shown by natives, as giving the maximum flood rise of a hill torrent, should not necessarily be distrusted because they differ in level on the two banks. With great falls in the bed, and consequent high velocity, the flood-water will swirl up from 3 feet to 5 feet higher on one bank than on the other. In the absence of other information, much may be learnt by searching for the dry chips and grass which, floating on the surface of the water, stick to the bushes and banks, and define the flood-rise long after other marks have disappeared.

Where the road skirts the foot of a great mountain-range, very peculiar conditions of drainage are met with. The fall in the bed of the mountain torrents diminishes suddenly from perhaps 200 feet in one mile to 30 feet in the next. The consequence is that vast quantities of silt are brought down and deposited in the lower reaches, where the beds of the torrents are constantly, though gradually, being raised, until the watercourses run along ridges considerably above the general level of the country. In ordinary floods the ground below and between these watercourses has merely got to carry off its own drainage; but in heavy rains the detritus brought down by the torrents chokes them up as the velocity diminishes. The pent-up waters of two neighbouring streams, topping the lip of the ridges that carry them, then spread over into the lower ground between them, which at other times is perhaps almost dry. The best plan in such cases is to build culverts or bridges on the ridges, and on the lower ground to have metalled gaps, sufficiently wide to allow the floods to cross them at a low velocity and at a fordable depth for carts, say from 1 foot 6 inches to 2 feet. It is also advisable to cut down the lip of the ridge, to within 1 foot or 2 feet of the ordinary flood-level to facilitate extraordinary overflows, and to let them move gradually on to the metalled gaps, which would otherwise be destroyed by the rush of water. These are generally protected on the upper and lower sides by masonry drop-walls, sheet piling, or, in sandy soil, a line of circular brickwork wells. The interior space is filled with boulders, coarse gravel concrete about 2 feet thick, or, where nothing else is procurable, brushwood fascines, pegged together

and covered with a layer of good metalling. The only means of preserving the gap from cutting up being to take the water over it in one smooth, unbroken sheet, the ground above and below it, for 300 feet or 400 feet, is cut down into a gentle uniform slope, paved with boulder pitching, the ends of the gap being further protected by great pear-shaped earthen groins, secured with sheet and fender piles. Some gaps on the Lahore and Peshawur road are over 2,000 feet in length, but are not found objectionable in practice.

To conclude the subject of surface drainage, it may be remarked that, whereas in Europe it may be controlled and even coerced over large catchment basins, it must in the Tropics either be entirely humoured or managed by subdivision into small areas.

The shape generally given to the metalled road-surface in cutting along a mountain side is a slope of 1 in 18 from the outside to the inside. It has been objected to this slope that it converts the road into a drain, which is cut away and becomes impassable in heavy downpours; and in some of the Madras hill roads the slope runs from the inside to the outside. Both systems have their respective advantages; but, on the whole, the inside slope is preferable when the cross drains are sufficiently large and numerous, and the side-drains rocky or properly protected by boulder paving. The usual practice is to adopt the outside slope until the drains are all built and the side-slopes have taken their bearings, when, as a permanent arrangement, the road is finished and metalled with an inside slope.

The metalling, which is generally cheap and good, consists of a 9-inch layer of broken granite, kunkur rock, or coarse slate shingle, and does not materially differ from an ordinary macadamised surface.

The usual width of a mountain cart-road varies from 18 feet in open ground to 12 feet along cliffs or in very difficult places; the maximum gradients varying from 1 in 18 to 1 in 25. The cost is very uncertain, and in no other kind of work is it more unsafe to estimate for one case from the known data of another. As an illustration, however, the following are the estimated costs of some of the lines :—

Chukrata Road	£1,500 a mile.
Bridging light; labour pretty abundant.	
Kangra Valley Road	£2,300 a mile.
Bridging very heavy; labour abundant.	
Dalhousie Road	£2,700 a mile.
Excavation very heavy; labour scarce.	

To each of which, perhaps, £300 a mile might be added for metalling.

The farther end of the Hindustan and Thibet road, which may be described as an unmetalled mule road, 7 feet in width, with gradients of 1 in 6 to 1 in 4, cost about £500 per mile.

A Himalayan cart-road, if only from its small local traffic, great prime cost, and incessant repairs, would never pay as a commercial speculation and apart from its vast political and military importance to the British Government. Wire tramways, worked by water power obtainable from the mountain torrents, is a step in the right direction, and will probably supersede other means of communication.
